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THE MOSASAUR
The Journal of the Delaware Valley Paleontological Society

Co-Editors

William B. Gallagher
Bureau of Natural History
New Jersey State Museum
New Jersey Department of State
CN-530
Trenton, NJ 08025-0530

Earle E. Spamer
Academy of Natural Sciences
1900 Benjamin Franklin Parkway
Philadelphia, PA 19103-1195

Associate Editors

Donald Baird
Michael J. Balsai

Stephen J. G. Farrington — *Business Manager*

Bruce Mohn — *Cover Artist*

Data Entry

Marcia Bell
Marjorie Gallagher

Reviewers for Volume 5

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Peter Dodson
Ralph Eschelman
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David C. Parris
Robert W. Purdy

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COVER — A reconstruction of the terrain at the Port Kennedy, Pennsylvania, sinkhole that preserved a Late Irvingtonian fauna and flora. (See the paper by Daeschler, Spamer, and Parris in this volume.) Rendered by Bruce Mohn, Copyright © Bruce Mohn.

The Delaware Valley Paleontological Society thanks the Department of Malacology, Academy of Natural Sciences of Philadelphia, for the facilities to produce the camera-ready pages of this volume. Page composition by Earle Spamer.

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The Cretaceous/Tertiary Mass Extinction Event in the Northern Atlantic Coastal Plain

WILLIAM B. GALLAGHER
Bureau of Natural History, New Jersey State Museum
New Jersey Department of State, CN-530
Trenton, New Jersey 08625-0530
and
Department of Geological Sciences
Wright Geological Laboratories
Busch Campus, Rutgers University
Piscataway, New Jersey 08855-1179

ABSTRACT — The Inner Coastal Plain in New Jersey and Delmarva is underlain by a Campanian (Upper Cretaceous) to Thanetian (Paleocene) stratigraphic sequence containing fossil assemblages from before, during and after the K/T boundary mass extinction event. The lithostratigraphic framework and the microfossil zonation of these faunal changes is reviewed. Microstratigraphic analysis of the sequence reveals that dominant marine organisms of the Upper Cretaceous such as ammonites and oysters are selectively extirpated at the K/T boundary, while those organisms with a non-planktotrophic reproductive strategy were the surviving marine invertebrates. Comparative taphonomy is applied to two fossil assemblages in the sequence to demonstrate the differences between reworked taphocoenoses of nearshore and estuarine environments and those of deeper-water taphocoenoses. A complete synonymy for all New Jersey K/T vertebrate taxa is presented, and all valid taxa are plotted on a stratigraphic range chart with guild/niche information about each group. It is concluded that the methodology of comparative taphonomy can be a useful tool in determining the difference between transported, reworked fossil assemblages produced by physical events like storms, and those assemblages which accumulted in deeper-water settings where modification was primarily biological. The mass extinction event as recorded in this sequence was gradual, but exacerbated by a sharper mass mortality at the end of the Cretaceous; diversity rebound to pre-K/T levels did not occur until the Thanetian. Plankton crash most drastically affected those organisms with a planktotrophic larval stage. The drop in plankton biomass was mediated upward in the food chain to duraphagous predators (and to those who ate them) by way of the die-off in previously abundant Cretaceous mollusks. Finally, it would appear that a combination of gradual climatic changes coupled with a sudden event like a bolide impact caused a protracted period of mass extinctions with suppression of full biomass productivity lasting well into the Paleocene.

1. Introduction

THE PROBLEM OF the nature, cause(s), and timing of mass extinction events has been a topic of controversy since Cuvier's work on the fossil vertebrates of the Paris Basin (Faul and Faul, 1983). Cuvier favored rapid catastrophic extinctions, but his has been decidedly the minority view within a geological community dominated by the concept of Lyellian uniformitarianism during the last century and a half (Gould, 1984). Indeed, mass extinctions were largely ignored as an interesting research topic until recently; many workers chose to focus on speciation and other aspects of evolutionary paleoecology to explicate the major features of the fossil record. As recently as 1957, for instance, Loeblich and Tappan could espouse a stratigraphic gap to explain the turnover in planktonic foraminifera between the Cretaceous and Tertiary periods. Newell's work (1962, 1965, 1966) and his debate with Bramlette (1965a, 1965b) refocused discussions of mass extinctions on their stratigraphic, paleoecological and evolutionary significance. Both Newell and Bramlette, in keeping with long geologic tradition, favored essentially gradualist views of mass extinctions, linking them to transgressive-regressive cycles.

With the advent of plate tectonic theory, transgressive-regressive gradualistic models were adapted to the plate tectonic paradigm to explain the Permo-Triassic mass extinction which decimated marine invertebrates (Schopf, 1972; Simberloff, 1972). Plate tectonic controls on diversity were generalized for much of the fossil record (Reyment, 1969; Valentine and Moores, 1970, 1972; Valentine, 1973; Cooper, 1977).

While the Permo-Triassic event may have been the largest mass extinction in the marine realm, much of the attention focused on mass extinctions in the last decade has been directed at the Cretaceous-Tertiary (K/T) boundary. This datum marks the disappearance of the dinosaurs as well as numerous typically Mesozoic marine forms including the globotruncanids among the microplankton, rudists, exogyrids, inoceramids, ammonites among the larger invertebrates, and plesiosaurs and mosasaurs among the macrovertebrates some 66.5 million years ago.

With the discovery of anomalously high levels of iridium at the K/T boundary in Italy, Denmark, and New Zealand, Alvarez et al. (1980) reopened the debate regarding the causes and timing of major mass extinctions, especially the K/T event. They proposed that the iridium concentrations were the product of global fallout from an asteroid impact, which created a planet-encircling dust cloud that severely restricted or terminated photosynthesis for several months to several years, disrupting both marine and terrestrial ecosystems and leading to mass extinction.

Numerous studies followed, some offering corroborative evidence for the Alvarez hypothesis (Smit and Hertogen, 1980; Ganapathy, 1980; Kyte et al., 1980; Orth et al., 1981; Smit and Klaver, 1981; Luck and Turekian, 1983; Alvarez et al., 1984; Bohor et al., 1984; Wolbach et al., 1985; Kyte and Wasson, 1986; Lichte et al., 1986; Kyte and Smit, 1986; Bohor et al., 1987), while others vigorously refuted it (Clemens et al., 1981; Hickey, 1981; Archibald and Clemens, 1982; Rampino and Reynolds, 1983; Zoller et al., 1983; Officer and Drake, 1983, 1985; Ekdale and Bromley, 1984; Stanley, 1984; Carter et al., 1986; Officer et al., 1987;

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Hallam, 1987). Some workers offered alternative impact scenarios (Emiliani, 1980; Hsu, 1980; Hsu et al., 1982). Much of the early research and debate on the subject is summarized in Silver and Schultz (1982). More recent studies are contained in Sharpton and Ward (1990).

Raup and Sepkoski (1982) offered a statistical verification of mass extinction events (including the K/T extinction episode) and then went on to propose a 26 million year periodicity to these events (1984). This cyclical extinction hypothesis relies heavily on statistical manipulation of large data sets derived from taxa-counting exercises based on the literature. Such manipulations are fraught with potential statistical error, as Lutz (1985, 1987) and others (Kitchell and Pena, 1984; Hoffman and Ghiold, 1985; Noma and Glass, 1987) have pointed out.

It is now clear that mass extinction studies must move beyond the realm of literature surveys and taxa-counting. To quote Raup (1986, p. 58), ". . . one of the challenges for future research is to do a much more thorough job of identifying the winners and losers, so that we have a better chance of learning exactly what environmental stresses were responsible for the disaster [at the K/T boundary]." This objective requires extremely detailed field analysis of specific sections and their contained faunas. What is needed is a microstratigraphic strategy that considers faunal changes in sections containing Maastrictian and Danian deposits.

One such section underlies the inner portion of the northern Atlantic Coastal Plain in New Jersey. The northern sector of the Atlantic Coastal Plain is a well-documented area that forms a naturally spatially restricted unit; to the north, the K/T sequence strikes out to sea, while to the south the Upper Cretaceous and Lower Tertiary beds thin and are overlapped and covered by younger strata in Virginia. Moreover, the K/T section in New Jersey is a classic column against which other sequences in the Atlantic and Gulf Coastal Plains are frequently compared; it is also intermediate in space between the historically important European sections and the thick Cretaceous and Tertiary deposits of the American Western Interior. Although the paleontology of these beds has been studied virtually since the inception of the science on this continent, no workers have looked closely at the faunal changes associated with the Mesozoic-Cenozoic transition in this area. This study is designed to correct that deficiency.

Part of the problem in dealing with the classic paleontology done in this region is the nature of the older studies. From the latter half of the nineteenth century into the early decades of this century, a number of excavations into the Inner Coastal Plain deposits were operated for a variety of economic purposes. Numerous pits produced sand and gravel for fill, clay for bricks, and marl for fertilizer. During the heyday of these mining operations, the early paleontologists had a wealth of exposure to study and a concomitant abundance of fossils to collect. Unfortunately, the science of stratigraphy was also in its formative years at this time, and so early collectors did not label their specimens as precisely as modern biostratigraphers might like. Add to this the confusion wrought by the variety of the early stratigraphic nomenclature, the paucity of exposure as a result of extensive soil development and plant cover, and the destruction of historically important outcrops due to urbanization; so that despite a long history of scientific study, our understanding of New Jersey Upper Cretaceous and Lower Tertiary deposits is still imperfect.

But besides the dearth of exposures caused by the decline of soft-sediment mining, additional complications in our knowledge of this sequence have arisen from traditional "layer-cake" interpretations of the stratigraphy and the application of sedimentation models largely derived from studies of classic Gilbertian delta deposits (for example, see Owens and Sohl, 1969). This "delta dogma" fails to account for some of the subtleties of faunal and facies changes both along strike within individual units and between units within the entire section.

Certainly the Lower to Middle Cretaceous beds have aspects of deltaic deposition; the Potomac Group probably progrades out over the continental shelf into the Baltimore Canyon Trough (Petters, 1976; Olsson, 1975). The Raritan Formation also exhibits many deltaic features, although a fluvial-tidal channel complex offers an appealing alternative interpretation, given the marine fauna found in the Woodbridge Clay Member. The Magothy Formation above the Raritan also contains marine fossils at some levels, and these marine assemblages mark the first appearance of the transgressive phases that typify the rest of the Inner Coastal Plain Upper Cretaceous to Lower Tertiary section. The faunal and sedimentological changes that occur in the superjacent Matawan, Monmouth, and Rancocas Groups reflect more than anything else the sea level changes characteristic of the interval.

Olsson (1963, 1975) and Petters (1976) have emphasized the importance of facies changes down dip, in the subsurface. It is also important to recognize facies along strike within a single unit. For instance, the upper part of the Navesink Formation in Monmouth County is strikingly different from the top of what is mapped as that same unit in Gloucester County. A similar situation occurs in the Mount Laurel Formation which also changes lithologically and faunally from its northeasternmost exposures to the southwest in Delaware (Gallagher, 1984). The Marshalltown and the Vincentown are examples of two other formations in the area that exhibit distinctive facies changes along strike.

Along any segment of southern New Jersey coastal area today, a varied complex of environments exists in close proximity to each other, while each environment maintains its own typical sedimentation regime and biota. The whole complex is thought to be migrating landward in response to Holocene eustatic sea level rise (Kraft et al., 1973). Sediment sampling via dredge, grab, and scoop along a transect from a deep-water continental shelf submarine canyon bottom across the shelf past the barrier island line into estuarine and fluvial environments shows that depositional environments can change rapidly within short distances; such a transect was carried out by the author on Cruise W-75 of the R/V *Westward* (Wilbur, 1985). The sedimentation patterns around barrier islands, tidal channels, and estuaries can be very varied; within a nautical mile one can pass from a substrate of coarse quartz sand with pebbles onto an organic-rich silty mud, as occurs in Delaware Bay (see Fig. 1). This sublittoral-barrier beach-tidal channel-estuarine lagoon-fluvial complex is offered here as a more appropriate actualistic model for some aspects of K/T facies changes and paleontology.

Other features of K/T sedimentology and paleoecology must be explained by unique oceanographic conditions associated with a smaller North Atlantic Ocean and the influence of a subequatorial Tethyan circulation (Barron and Peterson, 1989). New Jersey would have been a little farther south (30 to 35 degrees latitude; Smith and Bridan, 1977), along a coastline that was oriented more on a northeast-southwest line, facing a smaller Atlantic basin (900-1200 km width between Newfoundland and Ireland during the Late

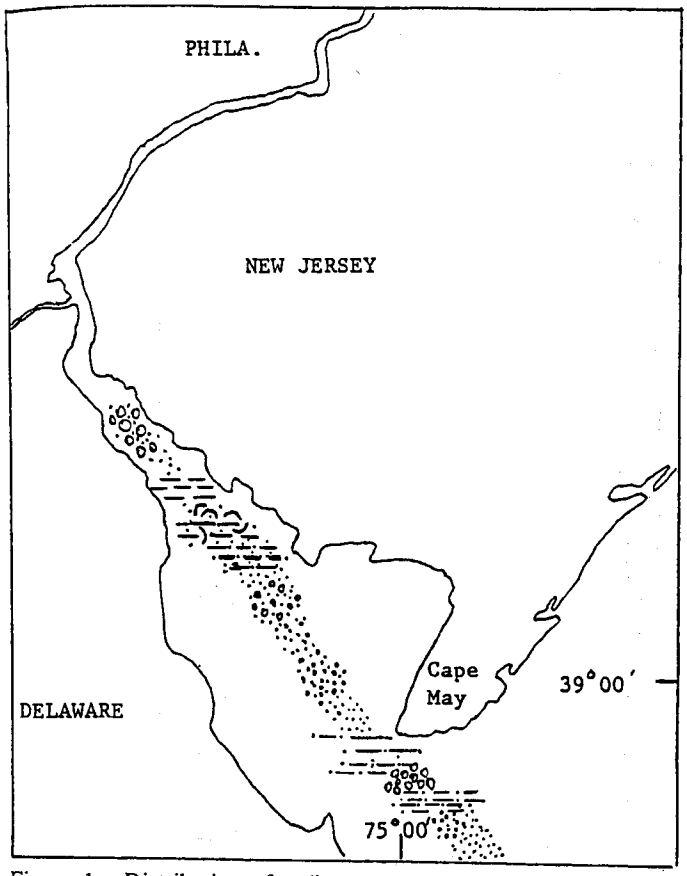


Figure 1. Distribution of sediment types on the inner continental shelf and in Delaware Bay. Data in Wilbur (1975). Symbols as in Fig. A-1 (Appendix).

Cretaceous; McKerrow, 1978). The primary current patterns were controlled by a warm Tethyan current pouring through a much wider area between the northern and southern continents than at present (Barron and Peterson, 1989). Lower latitudinal temperature gradients would have led to lower mixing rates of water masses and to widespread anoxia, as demonstrated by extensive deposition of black shales in the North Atlantic (Tissot, 1979; Kauffmann, 1984). Pulses of increased sea floor spreading rate may have expanded the volume of the mid-ocean ridge system, displacing oceanic water and causing sea-level rise; at the same time continental margins were subsiding as they moved away from the ridge and became cooler and denser (Reyment, 1969; Valentine and Moores, 1970; Rona, 1973; Cooper, 1977).

As the Atlantic opened, Tethys closed. Rotation of Africa into Eurasia and subsequent collision and accretion of micro-continents (Apulia, Iberia, the Hellenic blocks, Iran) around the end of Mesozoic time is suggested by a chain of ophiolites stretching from the Alps into the Zagros Range that appear to have been emplaced during the Late Cretaceous (Coleman, 1977; Blome and Irwin, 1985). This collisional, active tectonic style is in contrast to the passive trailing continental margin of eastern North America, where the chief effect of plate tectonic activity was the rise and fall of sea level.

The transgressive units of the K/T sequence in New Jersy are marked by glauconitic deposition. The "greensand marls" usually contain the most abundant marine faunas while regressive quartz sand units display less marine diversity. Today, nearshore sands exhibit less diversity than deeper-water environments because of the regular disturbance caused by wave action and tidal currents. Fig. 2 shows the variation in faunal diversity between the formations. The glauconitic units were probably deposited in low-energy environments at a low rate of deposition, and so represent condensed sections. It is possible that widespread anoxic conditions led to deposition of glauconite in shallower waters than those in which we see it forming today (Van Houten and Purucker, 1984).

Nearshore deposits may demonstrate some increases in diversity if input from terrestrial ecosystems is taken into account (Gallagher et al, 1986). Concentrations of bones from land animals, for example, would increase the diversity indices for some units, particularly transition and marginal environments. These mixtures of terrestrial and marine faunas offer tantalizing possibilities for correlation of land and marine assemblages, but the taphonomy of these deposits must indicate age equivalence rather than protracted reworking. Such deposits may reflect storm events along a barrier beach-tidal channel-estuarine lagoon complex, with storm wash-overs and surges providing the mixing energy. Some kinds of fossiliferous deposits may reflect seasonal storms or flooding, perhaps cyclically relating to Tethyan climatic influences such as monsoons (Gallagher and Parris, 1986; Gallagher et al., 1986; Gallagher, 1989b).

A major exception to the general pattern of onshore-offshore diversity differences is the diversity reduction evident within the Hornerstown Formation and the subsequent diversity increase in the limesand facies of the Vincentown Formation (see Fig. 2). At the base of the Hornerstown Formation, the Main Fossiliferous Layer (MFL) at the Inversand Pit at Sewell, Gloucester County, N.J., has produced some 64 species of invertebrates and vertebrates; just three meters above this, in what is essentially the same transgressive glauconitic lithology, the sparse and diminutive fauna consists of 14 species. The invertebrates are dominated, at this level, by "primitive" suspension-feeders such as ahermatypic corals, brachiopods, and sponges (Gallagher and Parris, 1985; Gallagher et al., 1986). At the transition between the Hornerstown and Vincentown, a widespread population of the brachiopod *Oleneothyris harlani* forms a high-density, low-diversity assemblage that would appear to be a sign of environmental stress (Feldman, 1977). Above this horizon, the limesand facies of the Vincentown Formation contains an abundant high-diversity assemblage that probably represents bryozoan patch-reef ecosystems.

The reduction of faunal diversity within the Hornerstown is not easily explained by sea-level change, since the regressive phase does not occur until the Hornerstown-Vincentown boundary. Moreover, the faunal replacement of typically Cretaceous forms such as ammonites and mosasaurs by Tertiary species takes place within the Hornerstown between the basal portion and the middle of the formation. This reflects the terminal Mesozoic extinction event, and so the Cretaceous-Tertiary boundary is placed within this formation on biostratigraphic grounds. The high diversity of the Vincentown limesand represents diversity rebound after the mass extinction and subsequent period of faunal recovery, specifically in a newly reorganized patch-reef community (Sheehan, 1985). The micropaleontological data from the New Jersey coastal plain support this interpretation, as we shall see in the next section.

In addition to surveying the micropaleontology of the New Jersey K/T section, the second section of this study will also review the stratigraphy of this sequence with a view towards establishing the lithostratigraphic framework of the biostratigraphic changes. The next three sections look at several

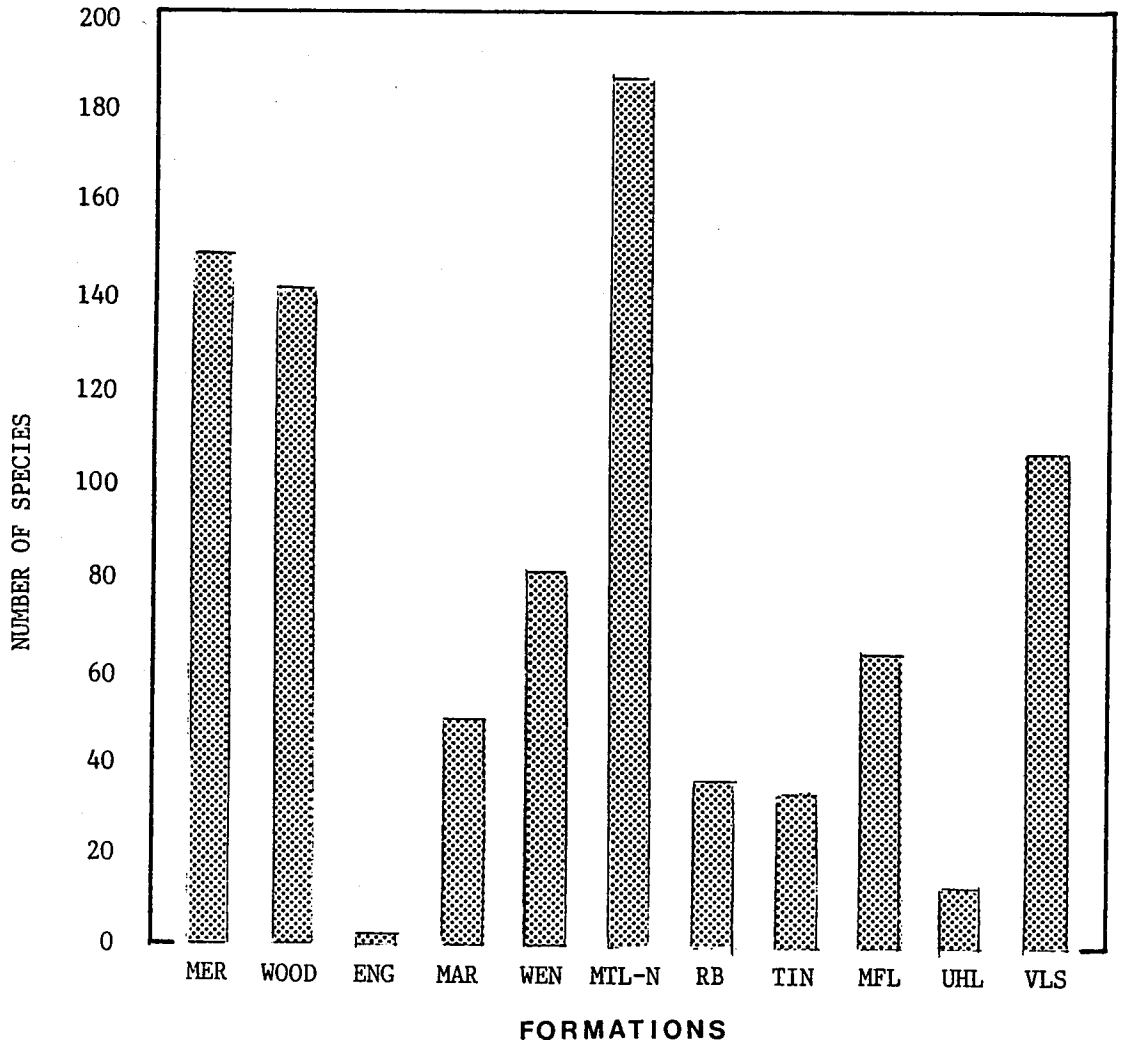


Figure 2. Faunal diversity in K/T formations of New Jersey.

questions inherent in any mass extinction study. Firstly, the third section will investigate the differential survival patterns among marine invertebrates across the K/T boundary in this section, and evaluate the possible paleoecological explanations for the observed faunal changes. The fourth section considers how taphonomic modes affect the extinction signal, specifically with regard to the problem of reworking and range determination. I will address this question by the method of comparative taphonomy, contrasting two taphocoenoses in order to demonstrate the differences between thoroughly physically reworked assemblages and minimally disturbed biologically altered assemblages. Along the way I will propose a new model for the taphonomy of mixed nearshore assemblages, with generalizations about physical versus biological factors in paralic and offshore environments. Thirdly, the next section will present a comprehensive vertebrate faunal list with synonymies and stratigraphic ranges for the New Jersey K/T sequence. There are several concerns here; one important question is how much of the faunal diversity is real, and how much is merely taxonomic artifact? Another component, considered in the conclusions, is the determination of winners and losers among ecological niches and guilds. My approach to the problems addressed in the fourth section combined review of the most recent taxonomic literature on the vertebrate taxa under consideration in this study with review of the collections of the several major museums housing large and historically important New Jersey K/T fossil suites. Finally in the last section I will integrate the previously presented material into a set of conclusions regarding the nature and timing of the K/T mass extinction event as represented in the deposits of the New Jersey coastal plain. Supporting data are presented in an appendix, consisting of twenty selected measured sections with commentary on microstratigraphy and faunal changes.

2. Stratigraphy and Micropaleontology of the Upper Cretaceous-Lower Tertiary Section in New Jersey

Precise stratigraphic control on the succession of faunas in the K/T section under consideration is highly desirable for extinction studies, but this kind of control has proven elusive for the reasons stated in the last section. The number of

outcrops available for correlation and collecting has diminished as the marl industry has declined, and as natural exposures have been destroyed due to development or for other reasons. The additional complication of facies changes in the section in an area of limited outcrop does not make this problem any more amenable to resolution. Still and all, a review of the stratigraphy of historically important sites combined with microstratigraphic analysis of sections available at the present can give us a reasonably accurate picture of the succession of depositional environments and faunal changes in the Upper Cretaceous and Lower Tertiary sections. What follows, then, is a review and summary of Campanian, Maastrichtian, Danian and Thanetian stratigraphic units with a view toward establishing a correct biostratigraphy for this interval in New Jersey.

In this paper, references to "Sections" will direct the reader to described measured stratigraphic sections that appear as an appendix. Lengthy tables are also grouped together to allow more convenient comparison of data presented in them.

Lithostratigraphy

The outcrop belts of the Matawan, Monmouth, and Rancocas Groups in New Jersey are shown in Figs. 3-5. Numbers on these maps locate the 20 measured stratigraphic sections that are described in the Appendix. A summary of New Jersey Coastal Plain chronostratigraphic and lithostratigraphic units appears in Table 1.

Upper Cretaceous Series
Campanian Stage

MATAWAN GROUP
(Fig. 3)

Merchantville Formation

Age—Owens et al. (1970) assigned an early Campanian age to the Merchantville on the basis of its ammonite fauna; this age assignment has been the traditional wisdom (Richards et al., 1958). Petters (1976), working largely with well samples, determined the Merchantville to be Coniacian to early Campanian by its foraminifera.

Lithology—The Merchantville is dark greenish gray to black greasy glauconitic silty micaceous clay to find sand. It is thin-bedded to massive. Silt, siderite, glauconite and lignite quantities vary along strike, with glauconite more common in the upper part of the section and in the southern part of the outcrop, while siderite, silt and lignite are more common in the middle of the formation to the north (Richards, 1956; Owens and Sohl, 1969).

Thickness—Ranges from 12 m to 18 m (40 to 60 ft) (Owens et al., 1970).

Fauna—Weller (1907) divided the New Jersey Upper Cretaceous formations into two types of faunal assemblages; a deeper-water Cucullaea assemblage and a shallower-water Lucina assemblage. He saw these two groups as roughly alternating in occurrence upward in the section as transgressive and regressive beds were deposited. The Merchantville fauna is a typical *Cucullaea* assemblage, and because of the diversity and abundance of its marine invertebrates it may be considered a Campanian standard, representitive of a biologically diverse and thriving Cretaceous marine community. For faunal lists of marine invertebrates, see Richards et al. (1962), Owens et al. (1970), and Gallagher (1984). Vertebrates found in this formation include chondrichthyans, osteichthyans, turtles, mosasaurs, crocodilians, and a few isolated dinosaur bones.

Extent—Traceable as a unit from Raritan Bay in the northeast to the eastern shore of Chesapeake Bay at Sassafras River in Maryland in the southwest.

Outcrop—In New Jersey, historically important exposures of the Merchantville Formation were associated with clay pits at Oschwald's Pits, Cliffwood, Monmouth County; Church's Pit near Bordentown, Burlington County; and Graham Brick Yard at Maple Shade, New Jersey (see Section 1). Various roadcuts and excavations have exposed the Merchantville from time to time, notably at the junction of Interstate 295 and Route 130 near Bordentown, and during construction of the Moorestown Mall. In Delaware, the Merchantville was exposed extensively along the banks of the Chesapeake and Delaware Canal before these outcrops were riprapped by the U.S. Army Corps of Engineers; today exposures are extant only in the Deep Cut section near Summit Bridge.

Subsurface—Petters (1976) describes the Merchantville Formation lithology from drill cores as "massive clayey greensand . . . in which sand-sized glauconite pellets are almost exclusively in a calcareous-clay matrix." He found several foraminiferal zones ranging in age from late Coniacian through early Campanian present in the subsurface Merchantville; Petters concluded that in the downdip direction the basal portion of the formation is time-transgressive. Olsson (1975) reported that the Merchantville thickens downdip at the expense of the underlying Magothy Formation, a more terrestrial unit. Sirking (1988) found the Merchantville Formation in the subsurface of Long Island, N.Y., on the basis of palynomorphs from well cores.

Woodbury Formation

Age—Late early Campanian (Owens et al., 1970; Olsson, 1975; Petters, 1976).

Lithology—Dark gray massive silty micaceous clay, weathering to a chocolate brown color with blocky fracture. Comminuted lignitic material is common at some levels.

Thickness—Maximum of 15 m (50 ft) in outcrop (Richards, 1956; Owens et al., 1970).

Fauna—The Woodbury fauna is notable for its preservation of original aragonitic shell material, including some very delicate forms, such as the scaphopod *Dentalium subarcuatum* Conrad. The invertebrates typify Weller's (1907) *Lucina* assemblage; this is an inner shelf marine fauna. Full marine salinity prevailed in the Woodbury waters, as indicated by the presence of the corals *Astrangia cretacea* (Bolsche), *Micrabacia cribraria* Stephenson, and *Trochocyathus woolmani* Vaughan. Ammonites include the common Campanian forms *Placenticeras placenta* (Dekay) and *Baculites ovatus* Say. In the way of vertebrates, the Woodbury produced the celebrated type specimen of *Hadrosaurus foulkii* Leidy; found associated with this skeleton were the teeth of a shark, *Scapanorhyncus texanus* (Roemer) and the tooth of a teleost, *Enchodus ferox* Leidy. In addition, chelonian remains have been found in this unit. For more complete faunal lists, see Richards (1956), Richards et al. (1962), Gallagher (1984), and Gallagher et al. (1986).

Extent—In New Jersey, from Raritan Bay in the northeast to Gloucester County in the southwestern part of the outcrop belt. Although Owens et al. (1970) did not recognize the presence of the Woodbury Formation in Delaware, field work by the present author has established that a unit lithologically indistinguishable from the Woodbury is present at the Deep Cut section along the north bank of the Chesapeake and

Table 1. Chronostratigraphic and lithostratigraphic units of the New Jersey Coastal Plain.

Chronostratigraphic Units			Lithostratigraphic Units	
System	Series	Stage	Group	Formation
Tertiary	Eocene	Ypresian		Manasquan Shark River
T	Paleocene	Thanetian	Rancocas	Vincentown
		Danian		Hornerstown
K	Upper	Maastrichtian	Monmouth	Tinton \ New Red Bank \ Egypt Navesink Mount Laurel
Cretaceous		Campanian	Matawan	Wenonah Marshalltown Englishtown Woodbury Merchantville
		Santonian-Cenomanian		Magothy Raritan

Delaware Canal near Summit Bridge, New Castle County, Delaware.

OUTCROP—Generally along stream banks in the area of its extent, but especially in Camden and Gloucester Counties where it is most typically developed. Numerous excavations have also temporarily exposed the Woodbury Formation, especially pits and road cuts in the vicinity of Bordentown, Burlington County, N.J. The outcrop along the tributary to Cooper River that produced *Hadrosaurus foulkii*, informally dubbed Hadrosaurus Run here, is still available and has been used for the stratigraphic section of the Woodbury Formation given in Section 2.

SUBSURFACE—The Woodbury increases in thickness downdip at the expense of the overlying Englishtown Formation (Olsson, 1975; Petters, 1976).

ENGLISHTOWN FORMATION

AGE—Early late Campanian (Petters, 1976) or late early Campanian (Owens et al., 1970).

LITHOLOGY—Originally this unit was called the Hazlet sand, then the Columbus Bed (Salisbury, 1898). It was defined as a yellow or brown ferruginous sand. Knapp, writing in Weller (1907), first used the term "Englishtown Formation" to describe the sandy unit between the Woodbury and Marshalltown Formations, the name "Columbus" being preoccupied. Richards' (1956, p. 73) description of the formation succinctly captures the essentials of the classic Englishtown:

> The Englishtown is a conspicuous bed of white or yellow quartz sand that is slightly micaceous and glauconitic. Some beds are locally cemented by iron oxide to form rather massive deposits of sandstone. There are a few lenses of clay or clayey sand, especially in the upper part of the formation, but these are probably not continuous. Cross-bedding is characteristic of some phases of the Englishtown.

Owens and Sohl (1969) subdivided the Englishtown into three lithofacies: 1) in the thicker northern part of its outcrop, the formation is composed largely of cross-bedded sand; 2) in the central part of the outcrop belt, the Englishtown is intercalated sand and dark carbonaceous clay; 3) to the southwest along strike the formation thins and becomes a massive dark-colored silty fine sand. The bulk of the formation is composed of moderately- to well-sorted quartz sand with subsidiary mica, feldspar, and weathered grains of glauconite; clays and silts contain abundant mica and lignite particles (Owens et al., 1970).

Reed (1960) looked at the heavy minerals, and described the formation as consisting "of a white or tan, slightly glauconitic, micaceous and lignitic, well-sorted, horizontally-bedded, fine-grained silty quartz sand, which in some places contains laminae of clay." She characterizes this sand as being present over most of the outcrop belt, but notes that in the northeastern portion of the Englishtown there are cross-bedded sands and lignitic clays.

THICKNESS—36.5 to 42 m (120 to 140 ft) thick in the northeast; 6 to 12 m (20 to 40 ft) thick in the southwest (Richards, 1956; Owens and Sohl, 1969; Petters, 1976).

FAUNA—The Englishtown has traditionally been regarded as barren of fossils in outcrop (Richards et al, 1958) although specimens are known from this unit in New Jersey from deep well sections. For instance, NJSM 8655, attributed to the Englishtown, is a lot containing specimens of fragments of *Turritella* sp. and *Granocardium tenuistriatum* (Whitfield) from a depth of 370 m (1220 ft) in a well at Lavallete, Ocean County, N.J. Owens et al. (1970) reported a nearshore fauna with some estuarine elements from the uppermost foot of this formation at the Chesapeake and Delaware Canal in Dela-

ware, and fossil occurrences are starting to turn up in the Englishtown of New Jersey (see Kuehne, 1993, this volume).

EXTENT—From Raritan Bay on the northeast to the eastern shore of Chesapeake Bay in the southwest (Owens et al., 1970).

OUTCROP—The best exposures are around the type locality in Monmouth County, and in the Rancocas Woods State Park in Burlington County, N.J. (see Section 3). In the Deep Cut section of the Chesapeake and Delaware Canal there is an exposure of this unit nicely sandwiched between the Woodbury below and the overlying Marshalltown, representing a complete regressive-transgressive cycle of deposition.

SUBSURFACE—Olsson (1975) noted that the Englishtown thins downdip and is replaced by the Woodbury. Petters (1976) reports that in well sections the formation becomes finer-grained. He believes it to be a more landward facies of the Marshalltown and the underlying Woodbury.

MARSHALLTOWN FORMATION

AGE—Early late Campanian (Owens et al., 1970), or late Campanian (Petters, 1976).

LITHOLOGY—When Knapp (writing in Salisbury, 1898) first named the Marshalltown Formation, he characterized it as consisting of a "good marl" in Salem and Gloucester Counties while to the northeast it became "a micaceous, black, greasy clay or fine ashy sand-marl." Knapp reiterated and clarified this description in Weller (1907, p. 17): "The Marshalltown bed, while maintaining a uniform thickness, changed from a sandy marl in Salem County to a clay and sand with beds of marl in Monmouth County." This definition was the one traditionally followed by most workers (for instance, see Richards, 1956), at least until recent years when the United States Geological Survey studies apparently disregarded the original definition of the unit and arbitrarily placed the clay and sand beds in the Englishtown, reserving the term "Marshalltown" to describe the silty micaceous glauconite sand that predominates in the southwestern part of the outcrop belt (Owens and Sohl, 1969; Owens et al., 1970). Other students (Gallagher et al., 1986; Parris et al., 1987) have favored retaining the original definition despite the difference between the glauconitic facies and the more lignitic, clayey and quartzose facies.

THICKNESS—4.6 m to 6 m (15 to 20 ft) (Owens and Sohl, 1969), or 14 m (45 ft) (Richards, 1956; Petters, 1976), depending on which formation definition is accepted.

FAUNA—The glauconitic facies in the southwest contains at some localities an abundant and diverse fauna of marine invertebrates characterized by the zone fossil *Exogyra ponderosa* Roemer. This genus forms shellbeds that typify the oyster bank communities of the Upper Cretaceous section in the Gulf and Atlantic Coastal Plain during the Campanian and Maastrichtian (Stephenson et al., 1942). The non-glauconitic facies has produced numerous vertebrate fossils at Ellisdale, Monmouth County, N.J. For faunal lists, see Richards et al. (1958, 1962), Owens et al. (1970), Gallagher (1984), Gallagher et al. (1986), and Parris et al. (1987).

EXTENT—Traceable as a unit from Raritan Bay on the northeast to Sassafras River area on the eastern shore of Chesapeake Bay in Maryland on the southwest (Owens et al., 1970).

OUTCROP—The glauconitic facies is exposed around Woodbury and Swedesboro in Gloucester County; the non-glauconitic facies is best seen at Ellisdale in Monmouth County (Gallagher, 1984; Gallagher et al., 1986; see Sections 4 and 5).

SUBSURFACE—According to Olsson (1975), the Marshalltown thickens downdip overlying first the Englishtown and then the Woodbury. It loses its formational identity in the far subsurface.

WENONAH FORMATION

AGE—Middle late Campanian (Owens et al., 1970), or basal Maastrichtian (Olsson, 1975).

LITHOLOGY—Light olive gray to dark gray thin-bedded to massive, poorly-sorted silty micaceous fine quartz sand, with abundant finely comminuted lignitic particles concentrated in laminae in some beds. There is also wavy and cross-bedding in places. Glauconite is a minor component. The Wenonah grades conformably upward into the overlying Mount Laurel Formation, making it difficult to separate the two units for mapping purposes (see Lewis and Kümmel, 1910-1912). The two formations have frequently been separated largely on the basis of fossils (Richards, 1956). This is mixing biostratigraphy with lithostratigraphy, and it has been argued elsewhere (Gallagher et al., 1986) that the two units should be combined into a single formation, the Mount Laurel.

THICKNESS—From a maximum of 18 to 21 m (60 to 70 ft) thick in the central part of the outcrop belt near Trenton to a minimum of 4.5 m (15 ft) in the southwest, it coarsens to the southwest so that the Wenonah becomes inseparable from the Mount Laurel Formation (Owens and Sohl, 1969; Owens et al., 1970).

FAUNA—Internal casts of fossils are scattered through the formation, and some thin concentrations of vertebrate fossils are present. The invertebrates such as *Inoceramus* indicate a marine environment, and on the whole the fauna is a *Lucina* assemblage partially recurrent from the Woodbury Formation (Richards, 1956).

EXTENT—From Raritan Bay on the northeast through the west-central part of the Inner Coastal Plain to pinch-out in Salem County. The Wenonah is not recognized in Delaware.

OUTCROP—Well-exposed in the banks of Big Brook, west of Boundary Road, Marlboro, Monmouth County, N.J. Virtually indistinguishable from the Mount Laurel in most of the southern part of the Matawan Group outcrop belt (see Sections 4, 5, and 9).

SUBSURFACE—Downdip, the formation grades into clays, sandy silts, and silts (Olsson, 1975).

MONMOUTH GROUP
(Fig. 4)

MOUNT LAUREL FORMATION

AGE—Late Campanian (Owens et al., 1970; Olsson, 1989); early Maastrichtian (Olsson, 1975; Petters, 1976; Jordan and Smith, 1983).

LITHOLOGY—Light gray to dark brown medium to coarse quartz sand with pebbles; in some places these sands are intercalated with dark clays, especially to the northeast. In other localities, particularly to the southwest, these beds may be indurated by iron compounds. It is more glauconitic in the southwest.

THICKENESS—From 6 m (20 ft) in the northeast to 21 m (70 ft) in the southwest (Owens et al., 1970).

FAUNA—This formation constitutes the northern extension of the *Exogyra cancellata* zone. It is characterized by an extensive marine invertebrate fauna, and espcially by the appearance of large numbers of *Belemnitella americana* (Morton). Because of the lithological and faunal similarities,

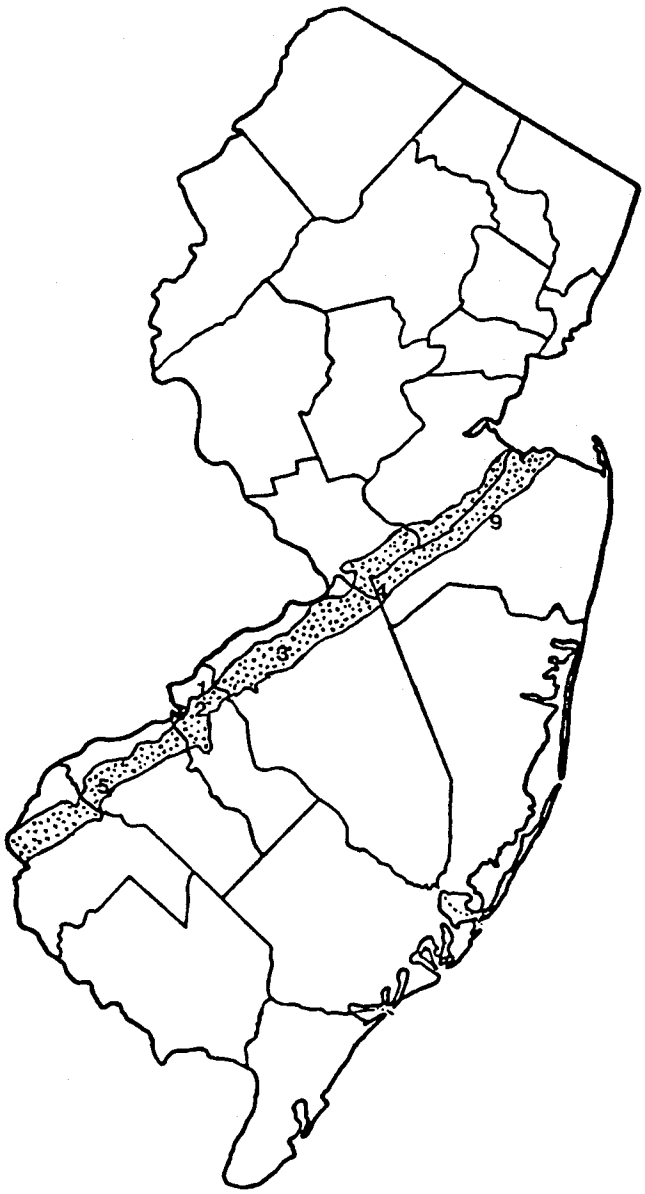


Figure 3. Outcrop belt of Matawan Group, Upper Cretaceous, New Jersey.

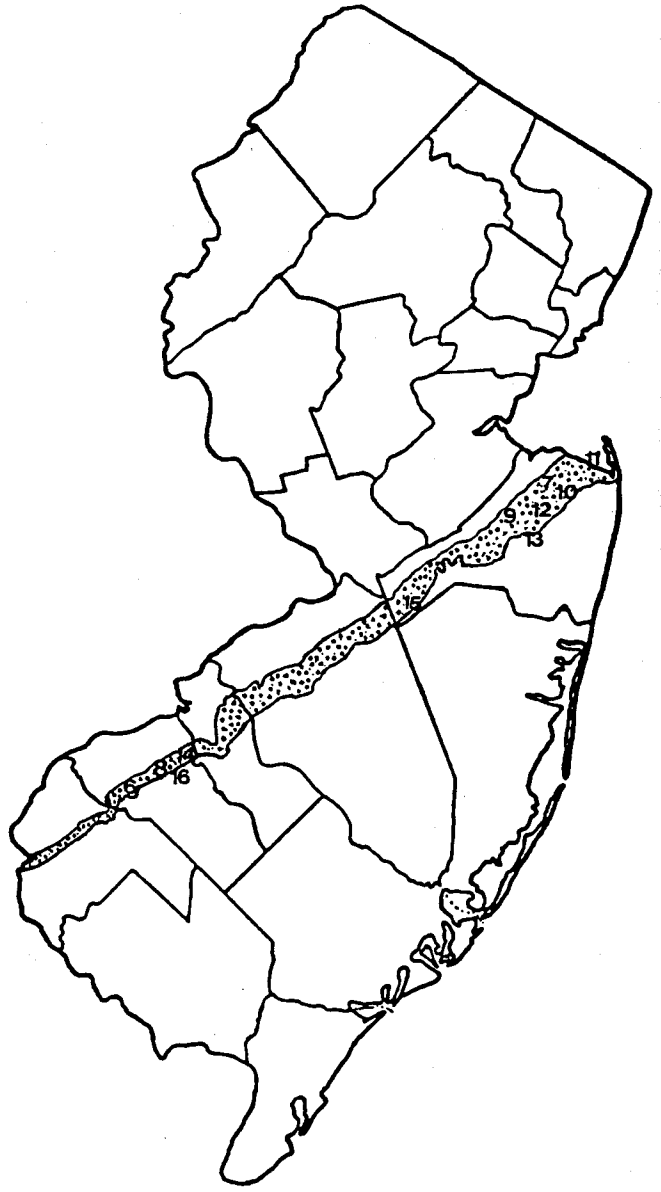


Figure 4. Outcrop belt of Monmouth Group, Upper Cretaceous, New Jersey.

especially in the southwestern part of the outcrop belt, the Mount Laurel has often been discussed with the overlying Navesink Formation (Weller, 1907; Richards, 1956; Richards et al., 1958, 1962). However, in Delaware the Mount Laurel Formation as exposed at the Biggs Farm site on the south bank of the Chesapeake and Delaware Canal near Saint Georges has yielded a unique fauna (Richards and Shapiro, 1963) and other workers have more recently made a faunal distinction between the two formations (Owens et al., 1970). For extensive faunal lists, see the references cited above plus Gallagher (1984) and Gallagher et al. (1986).

EXTENT—From Monmouth County on the northeast to the eastern shore of Chesapeake Bay in Maryland on the southwest (Owens et al., 1970).

OUTCROP—Old excavations along Route 34, Holmdel, Monmouth County; in streambanks along Hop Brook, Big Brook and Crosswicks Creek, Monmouth County; Irish Hill, Camden County; along the banks of Chestnut Branch in Sewell, Gloucester County; at Mullica Hill, Gloucester County, N.J. (see Sections 6, 7, and 8).

SUBSURFACE—The coarsening upward of the Wenonah Formation into the Mount Laurel is not noticeable in the subsurface, so that the two units cannot be distinguished downdip (Olsson, 1975; Petters, 1976).

NAVESINK FORMATION

AGE—Late Campanian to early Maastrichtian (Owens et al., 1970); early Maastrichtian (Olsson, 1975, 1989; Petters, 1976; Jordan and Smith, 1983).

LITHOLOGY—In its lower portion and especially to the north, the Navesink is predominantly a glauconitic sand, deep

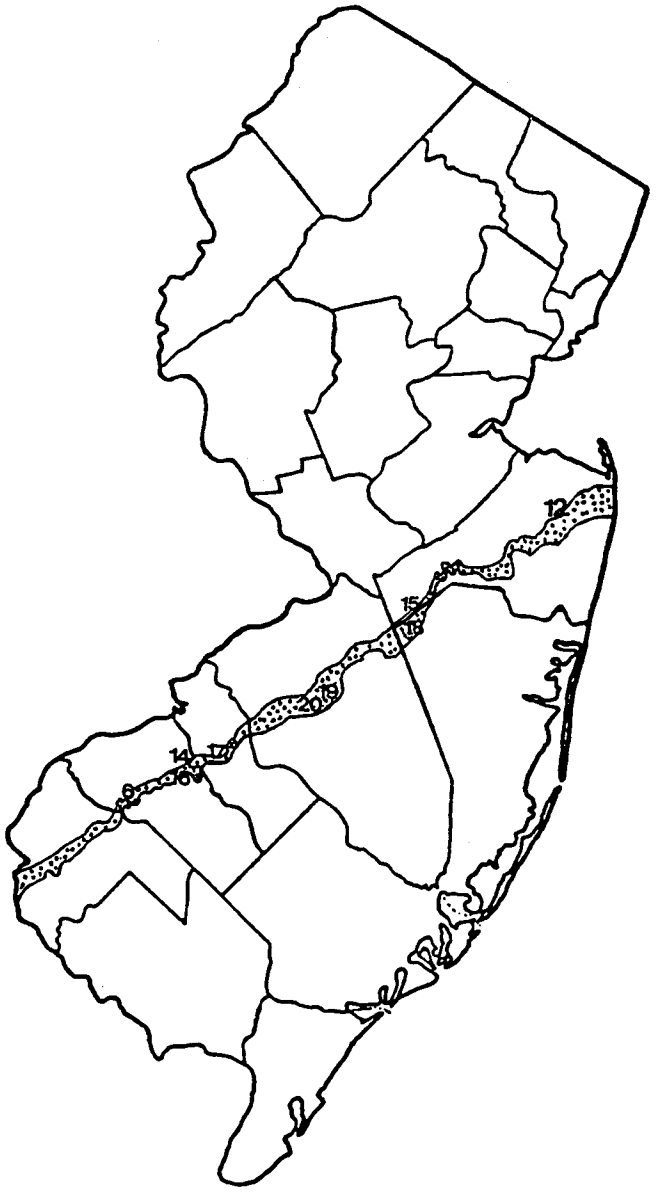


Figure 5. Outcrop belt of Rancocas Group, Upper Cretaceous-Paleocene, New Jersey.

dusky green in color. Toward the south and in the upper portion, it is less glauconitic and more clayey with more lignite and quartz granules. Here it assumes a dusky brown color, from which it derives its informal name, the "chocolate marl." The contact with the underlying Mount Laurel Formation is generally sharp and disconformable. It is moderately to poorly sorted, medium to coarse grained, with vivianite nodules present in places. (Gallagher, 1984; Gallagher et al., 1986.)

THICKNESS—From 10.6 m (35 ft) maximum in the central part of the outcrop belt to 1.5 m (5 ft) in the southeast (Owens et al., 1970).

FAUNA—The Navesink is in the *Exogyra costata* zone and is typified by oyster bank assemblages dominated by *E. costata*, *Pycnodonte convexa* and *Agerostrea mesenterica*. At lower levels, *Belemnitella americana* is abundant, and a distinctive small brachiopod, *Choristothyris plicata*, occurs. There is a diverse *Cucullaea* fauna present, and various marine vertebrates are also found. Also, this unit has yielded the occasional dinosaur specimen, such as *Hadrosaurus minor* (Marsh) and *Dryptosaurus* [*Laelaps*] *aquilungis* (Cope). For more extensive lists, see Richards et al. (1958, 1962), Gallagher (1984), and Gallagher et al. (1986).

EXTENT—From Raritan Bay at Atlantic Highlands, Monmouth County, in the northeast to the Delaware River in Salem County in the southwest. Although not recognized in Delaware, this may be due to onlapping and lack of outcrop; the Navesink's correlative unit in Maryland is the Severn Formation.

OUTCROP—The Navesink is commonly exposed along streambanks in the area of its outcrop in Monmouth County, especially along Poricy Brook, Big Brook, and Crosswicks Creek and its tributaries. It is also exposed in the bluff on Raritan Bay at Atlantic Highlands, where it trends out to sea. Historically there were a number of marl pits in the area that penetrated down to the Navesink. The sole remaining operation, the Inversand Pit at Sewell, Gloucester County, exposes the Navesink. This formation also crops out at Mullica Hill further south (see Sections 6, 7, 8, 9, 10, 11, 14, 15, and 16).

SUBSURFACE—The Navesink Formation grades into fine-grained silty glauconitic sand that is difficult to distinguish from other younger formations; Olsson (1963) has assigned this downdip facies a separate unit name, the New Egypt Formation. The glauconite content diminishes in the far downdip, and the Navesink merges with overlying units to form the base of the New Egypt (Olsson, 1975; Petters, 1976).

RED BANK FORMATION

AGE—Early Maastrichtian (Owens et al., 1970); middle Maastrichtian (Petters, 1976); late Maastrichtian (Olsson, 1989); middle to late Maastrichtian (Jordan and Smith, 1983).

LITHOLOGY—While the main body of the formation is a coarse yellowish to reddish brown feldspathic quartz sand, the basal portion is a silty clayey fine quartz sand, dark gray in color. Olsson (1963) called this lower bed the Sandy Hook Member, and named the upper part the Shrewsbury Member. In addition, U.S. Geological Survey workers recognize a third facies, a glauconitic sand overlying the Navesink Formation further to the southwest along strike. This unit replaces the lower Sandy Hook Member, grading into and resembling closely the underlying Navesink (Owens and Sohl, 1969).

THICKNESS—The Sandy Hook Member ranges from 3 m to 10.5 m (10 to 35 ft) thick in outcrop; at maximum the Shrewsbury Member is 24 m (80 ft) thick (Olsson, 1963). The glauconitic facies attains a thickness of 9 m (30 ft) near New Egypt in Monmouth County (Owens and Sohl, 1969).

FAUNA—Marine invertebrates are locally abundant in the lower fine-grained member, but fossils are scarcer in the coarse sand (Olsson, 1963). Weller (1907) regarded the Red Bank fauna as a *Lucina* assemblage.

EXTENT—Restricted to Monmouth County in the northeast section of the Upper Cretaceous outcrop belt.

OUTCROP—Matawan, Atlantic Highlands, Poricy Brook, Big Brook and Beers Hill, Monmouth County (see Sections 7, 9, 10, 11, and 12).

SUBSURFACE—Loses its formational identity in the shallow subsurface, merging into the New Egypt facies (Olsson, 1963, 1975).

Tinton Formation

Age—Middle to late Maastrichtian (Owens et al., 1970); late Maastrichtian (Olsson, 1989; Petters, 1976; Jordan and Smith, 1983).

Lithology—A light to moderate yellowish or reddish brown poorly sorted medium to coarse grained glauconitic quartz sandstone cemented by siderite.

Thickness—Maximum of 7.5 m (25 ft) thick (Owens and Sohl, 1969).

Fauna—There are some *Exogyra costata* specimens from this unit, although the oysters do not form the dense beds seen in underlying formations. The Maastrichtian zone fossil *Sphenodiscus lobatus* occurs in the Tinton, and various other mollusks are found as well. Weller (1907) regarded this fauna as a recurrence of the *Cucullaea* fauna, although it is somewhat less diverse than underlying *Cucullaea* assemblages. The most common fossils are the claws of the decapod crustacean *Callianassa mortoni* Pilsbry (Gallagher, 1984).

Extent—From Sandy Hook in the northeast to Roosevelt in the southwest; restricted to Monmouth County.

Outcrop—Beers Hill, Holmdel; Tinton Falls; both in Monmouth County (see Sections 12 and 13).

Subsurface—The Tinton is only found in the shallow subsurface in the restricted area of its outcrop belt; it merges into the New Egypt farther downdip (Olsson, 1963; Petters, 1975).

New Egypt Formation

Age—Late early Maastrichtian to Danian (Koch and Olsson, 1977); middle to late Maastrichtian (Jordan and Smith, 1983).

Lithology—Dark gray to chocolate brown massive burrowed glauconitic clayey sand to sandy glauconitic clay, indurated locally by siderite, and containing quartz as a minor constituent.

Thickness—In surface exposures in Monmouth County, 9 m to 10.6 m (30 to 35 ft) thick. In the subsurface along the Atlantic Coast in the same area it is 27 m (90 ft) thick (Olsson, 1963).

Fauna—Macrofossils are not common in outcrop, but can be found locally concentrated in fine-grained indurated layers. These are all marine invertebrates, including typical *Cucullaea* assemblage representatives such as the gastropods *Lunatia*, *Pyropsis*, *Turritella* and the bivalves *Exogyra costata*, *Pycnodonte*, *Crassatellites vadosus*, *Pecten venustus* and *Trachycardium*. Olsson (1963) reports the ammonites *Sphenodiscus lobatus* and *Baculites carinatus* from the formation.

Extent—In outcrop, only southern Monmouth County, particularly along Crosswicks Creek.

Outcrop—Along the banks of the Crosswicks Creek north of New Egypt, near the Ocean County-Monmouth County boundary (see Section 15).

RANCOCAS GROUP
(Fig. 5)

Hornerstown Formation

Age—Maastrichtian in basal portion, but main part Danian (Olsson, 1963, 1987; Richards and Gallagher, 1974; Koch and Olsson, 1977; Jordan and Smith, 1983); or entirely Danian (Minard et al., 1969; Owens et al., 1970).

Lithology—Grayish olive green to dusky yellowish green massive burrowed poorly to moderately sorted medium to fine grained clayey virtually pure glauconite sand.

Thickness—6 m to 9 m (20 to 30 ft) thick throughout its outcrop belt (Richards, 1956; Owens and Sohl, 1969).

Fauna—Although Weller (1907) and Minard et al. (1969) stated that the Hornerstown does not have abundant or diverse fossils, concerted collecting in recent years has yielded an interesting fauna from the basal part of the formation. Whereas previous workers focused on the shellbed at the top of the formation, the basal Main Fossiliferous Layer (MFL) is actually a more diverse assemblage of marine invertebrate and vertebrate remains. The middle of the formation has a less diverse, less abundant but no less interesting fauna as well. Moreover, careful scrutiny of museum collections coupled with a reading of the old reports reveals that many of Leidy's, Cope's and Marsh's type specimens from the K/T interval in New Jersey were probably obtained from the basal Hornerstown. The Hornerstown contains a Cretaceous marine fauna at its base, but in the middle and at the top has a decidedly Tertiary assemblage (Richards and Gallagher, 1974; Gallagher, 1984; Gallagher and Parris, 1985; Gallagher, 1986; Gallagher et al., 1986; Gallagher, 1988; Gallagher, 1989a). The basal MFL also has yielded a late Cretaceous avifauna (Olson and Parris, 1988).

Extent—From Raritan Bay in the northeast to the Sassafras River on the eastern shore of the Chesapeake Bay in Maryland (Owens and Sohl, 1969).

Outcrop—Once extensively exposed in numerous marl pits along the length of its outcrop belt, the Hornerstown is now limited largely to streambank outcrops, temporary excavations, and the single remaining marl mining operation, the Inversand Pit at Sewell, Mantua Township, Gloucester County, N.J. (see Sections 13, 14, 15, 16, 17, and 18).

Subsurface—The clay content of this unit gradually increases downdip until it loses its formational identity in the deep subsurface (Olsson, 1975).

Vincentown Formation

Age—Danian (Gallagher, 1984); Thanetian (Olsson, 1970; Jordan and Smith, 1983); or possibly Dano-Montian.

Lithology—There are several facies present in the Vincentown. The basal section of the formation contains glauconite in decreasing quantities; above the *Oleneothyris harlani* biostrome, which marks the Hornerstown-Vincentown contact, quartz sand content gradually increases until glauconite becomes a minor constituent. In some places this lower glauconitic quartz sand occurs in indurated layers. The middle to upper part of the formation, especially in the northeastern portion of the outcrop belt, is dominantly a light-colored massive quartz sand. To the southwest along strike, a third facies occurs. This is a yellowish gray clayey moderately to poorly sorted thin- to thick-bedded calcareous quartz sand to calcarenite, with glauconite as a minor constituent. This facies is abundantly fossiliferous, the limesands being largely composed in some layers of bryozoan fragments.

Thickness—Ranges from 7.5 m (25 ft) thick in the southwestern area to 30 m (100 ft) thick in the north in Monmouth County (Richards, 1956; Owens and Sohl, 1969; Olsson, 1975).

Fauna—At the base, the fauna is dominated by the brachiopod *Oleneothyris harlani*, with a subsidiary element composed of the oyster *Pycnodonte dissimilaris*. The quartz sand facies contains numerous but scattered marine invertebrates, especially bryozoan fragments and echinoid spines.

There are also some marine vertebrates found in the formation, notably elasmobranchs. Several isolated finds of snake remains (Gilmore, 1938) represent what was probably a large marine reptile, *Paleophis*. But the true abundance and diversity of the Vincentown fauna is found in the limesand facies. Up to 80% of the limesand is in places composed of bryozoan remains, mostly of one species, *Coscinopleura digitata* (R. Ramsdell, personal communication). Canu and Bassler (1933) recognized 85 species of bryozoa all together. There are also serpulid worms, a gorgonian, ahermatypic coral, several bivalves, a few gastropod species, some rare brachiopods, several crustacean genera, a crinoid, and a dozen species of echinoids (Gallagher, 1984).

EXTENT—From Monmouth County on the northeast to the eastern shore of the Chesapeake Bay in Maryland. The massive quartz sand facies dominates in Monmouth County, while the glauconite sand facies is prevalent in the Delmarva Peninsula. The limesand facies is restricted to the southwestern part of the outcrop belt in New Jersey. Even here it generally occurs in rather limited spatial areas suggesting lenses or patches.

OUTCROP—The type locality at Vincentown, Burlington County, is still the best outcrop. In the nineteenth century, the Vincentown calcarenite facies was extensively exposed in a series of pits in the vicinity of the type locality, where it was mined for use as agricultural lime. There are also outcrops further southwest along strike in the area of Big Timber Creek and its tributaries in Camden and Gloucester Counties (see Sections 16, 17, 18, 19, and 20).

SUBSURFACE—The Vincentown pinches out quickly downdip and is replaced by a silty facies (Olsson, 1975).

Micropaleontology of the K/T Section in New Jersey and Delaware

The first modern synthesis of Atlantic Coastal Plain micropaleontology as it relates to other areas of the world was Loeblich and Tappan's (1957) study of Paleocene planktonic foraminifera. This work asserted the usefulness of foraminifera in inter-regional correlation and applied foraminiferal biozonation to the so-called "Danian problem." The authors reviewed planktonic assemblages world-wide and compared them to Gulf Coastal and Atlantic Coastal Plain sections. This study helped establish the *Globotruncana* Upper Cretaceous assemblage as distinct from the Danian *Globigerina* assemblage. The authors assigned a Danian age to the Hornerstown Formation, but noted that it contains Cretaceous foraminifera in its basal part. They subscribed to the old Lyellian-Darwinian view of the K/T boundary, believing that the widespread change in foraminifera took place over some very extended period of time not represented in the geologic record due to extensive tectonism and non-deposition, rather than a major mass extinction event. It was not until the work of Newell (1962, 1966) and Bramlette (1965a) and their debate in the pages of Science (Newell, 1965; Bramlette, 1965b) that the concept of a world-wide massive extinction of planktonic forms at the K/T boundary became well established in the literature.

The most extensive micropaleontological work on the K/T sequence in the New Jersey Atlantic Coastal Plain is by Olsson (1958, 1963, 1964, 1970, 1975, 1987, 1988, 1989) and his students. In his early studies (1958, 1963), Olsson established the downdip facies relationships in the K/T section and named a new unit, the New Egypt Formation. This is largely a down-dip deeper water facies based on correlation of surface exposures with subsurface deposits by means of foraminiferal zones. Originally, he equated this new glauconitic unit with the shallower-water up-dip Navesink, Red Bank, Tinton, and Hornerstown Formations. Later (1975, 1987, 1988, 1989), Olsson seems to restrict its correlation to the Red Bank and Tinton. In some areas, notably the type section, the New Egypt crops out at the surface, as noted above.

Olsson (1963) believed that the classic *Lucina-Cucullaea* faunal alternation of Weller (1907) was more probably caused by changes in bottom environmental conditions than by changes in sea level. He emphasized the tectonic stability of the area and characterized the K/T interval as a time of quiet deposition on a stable continental shelf. While planktonic foraminifera were used to correlate from up-dip to down-dip sections, benthic forams were used for paleoecology; these indicated generally low oxygen conditions in the seafloor bottom during deposition of the predominantly glauconitic sediments.

Olsson (1963) noted the problem of recognizing the K/T boundary on lithologic grounds alone. He explained that facies changes are responsible for the disappearance of the Red Bank and Tinton Formations to the southwest, rather than the presence of an angular unconformity as favored by Minard et al. (1969). Olsson discounted any hiatus of deposition across the K/T boundary, which he placed within the lower part of the Hornerstown Formation in outcrop and within the upper New Egypt in the subsurface.

Olsson followed up this work with a careful look at the Cretaceous planktic foraminfera (1964) and the Paleocene planktic foraminifera (1970). Campanian foram faunas display a close relationship to those of the Tethyan realm, while Maastrichtian foram faunas in New Jersey are more Boreal in aspect. Olsson places the Campanian-Maastrichtian boundary between the Marshalltown Formation and the undifferentiated Wenonah-Mount Laurel Formation in New Jersey, while in Delaware the Mount Laurel Formation appears to be older and is assigned a Campanian age. The early Maastrichtian is characterized by the presence of *Hedbergella holmdelensis* in New Jersey, while *H. monmouthensis* is typical of the late Maastrichtian.

The Paleocene strata in New Jersey contain most of the planktonic zones recognized in world-wide correlation. The base of the Paleocene is defined by the *Globigerina edita* zone, known only from the subsurface; surface exposures of the Hornerstown are leached by acid weathering solutions. This zone contains a low diversity foraminifera fauna that Olsson interpreted as indicative of low biomass productivity. This assemblage is widespread in high and low latitudes; around the Atlantic Province the faunal homogeneity and low diversity is attributed to the K/T mass extinction event. Speciation occurs in the lowest three zones, and faunal differentiation becomes evident in the middle Paleocene. This interval of faunal recovery is estimated at 4 to 4.5 million years; after this the foraminifera faunas are distinguishable as middle and low latitude groups. The uppermost zone of the Paleocene, represented by the *Globorotalia velascoensis* assemblage, is partially missing, perhaps due to a disconformity (Olsson, 1970).

Petters (1976) extended Olsson's work, looking at the entire Upper Cretaceous section in both subsurface and outcrop. He noted the overly-simplistic interpretations of Cretaceous stratigraphy derived from "layer-cake" studies of limited exposures. Petters saw four major depositional sequences in the Upper Cretaceous of New Jesey, culminating in the oscillatory phase of minor transgressions and regressions lasting from early Campanian into the Danian. This

produced a fluctuation in the position of the strandline resulting in alternating deposition of shoaling sandy units and deeper-water glauconites. Correlation of these units in subsurface and outcrop was again achieved by planktonic foraminiferal biozonation. The restriction of the coarser units such as the Red Bank and Tinton Formations to the northern end of the coastal plain is attributed to episodic reactivation of a sediment source area to the north, controlling clastic input and the migration of the shore area. This study stresses three-dimensional facies relationships, and emphasizes that sediment changes are controlled by changes in depositional environment. Petters places the K/T boundary in the lower Hornerstown on the basis of micropaleontological data.

Koch and Olsson (1974, 1977) dealt with the difficulty of diagenetic leaching of outcrops at the K/T boundary in New Jersey by utilizing dinoflagellates to correlate subsurface foraminiferal zones with exposed units. Sarjeant (1974) discusses the utility of dinoflagellates for stratigraphic correlation; they are widespread and can give very good resolution, and because they have organic shells they are especially useful in rocks where diagenetic decalcification has occurred. Koch and Olsson demonstrate that the K/T boundary is present in the lower part of the Hornerstown Formation in outcrop. They also show that there is no angular unconformity below the Hornerstown along strike; the same dinoflagellate zone (*Deflandrea cretacea*) is present below the Hornerstown regardless of lithology.

Wolfe (1976) looked at palynomorphs from the Campanian and lower Maastrichtian beds of New Jersey, Delaware and Maryland. Pollen analysis of samples from these sediments showed sharp fluctuations in bissacate pollen content. These are interpreted as indicative of climate change; high bissacate periods are cooler, low intervals warmer. There were several climate cycles in the Upper Cretaceous sequence. Wolfe zones the various formations by pollen content, and places the Campanian-Maastrichtian boundary in the Navesink Formation. Samples were not taken above the Red Bank.

To the southwest in Delaware, the work of Jordan (1962, 1963, 1976) has followed a similar path, demonstrating the presence of the K/T boundary in that state largely on the basis of planktonic foraminifera zonation. Jordan (1976) has placed this boundary in the lower part of the Hornerstown Formation, and does not recognize an unconformity at the boundary. He reports a thin bentonitic layer closely associated with the faunal turn-over from Cretaceous to Paleocene foraminifera (1962).

In his more recent work, Olsson (1987, 1988, 1989) has reinterpreted New Jersey coastal plain stratigraphy in terms of sequence stratigraphic concepts (see Haq et al., 1987). He recognizes five cycles of sea level change in the portion of the coastal plain section under discussion here, KC 1 (Merchantville-Woodbury-Englishtown), KC 2 (Marshalltown- Wenonah-Mount Laurel), KM 1 (Navesink-Red Bank-Tinton), TP 1 (basal to upper Hornerstown), and TP 2 (uppermost Hornerstown-Vincentown). These cycles represent discrete sedimentary packets laid down during single intervals of sea level rise and fall, bounded by unconformities produced during the lowstands of the sea. Olsson and Wise (1987) make it clear from micropaleontological evidence that the major sequence boundary between KM 1 and TP 1 is located within the Cretaceous System and is of comparatively short duration; they state that the Hornerstown Formation "spans the K/T boundary". Indeed, Haq et al. (1987) depict a minor regressive phase before the end of the Maastrichtian in their sea level curve, with transgression starting before the K/T boundary.

In sum, the micropaleontological evidence places the K/T boundary within the lower part of the Hornerstown Formation, with no long-term, major break in deposition and no evidence for an angular unconformity. In this regard it is in agreement with the biostratigraphic evidence from invertebrate and vertebrate fossils.

3. Invertebrate Biostratigraphy and Paleoecology Across the Cretaceous/Tertiary Boundary in New Jersey

Benthic Communities

Weller (1907) was the first worker to characterize the Upper Cretaceous strata of New Jersey as having two distinct faunal assemblages. He named the recurrent fauna of the glauconitic units the *Cucullaea* assemblage; that of the non-glauconitic sands and clays he called the *Lucina* assemblage. The *Cucullaea* assemblage represented deeper-water transgressive phases, whereas the *Lucina* fauna was regarded as a shallow water regressive-phase group. The two groups alternated as sea level rose and fell.

Benthic faunal analyses have been prepared for the present study (Tables 2-4), which illustrate the observed turnover in trophic types in the Navesink and upper and lower Hornerstown Formations. This major faunal turnover occurs within the same glauconitic transgressive lithology and so does not reflect change of environment due to sea level fluctuation.

The glauconitic facies from the Marshalltown to the Tinton are characterized in places by the development of densely-packed oyster beds, dominated by the genera *Exogyra* and *Pycnodonte*. The smaller *Agerostrea* can also form a significant component of this community. These bivalves numerically dominate the beds in which they occur. They will frequently occur as broken valves, single whole valves, or entire articulated bivalved individuals together. The composition of these beds suggests an oyster "bank", with dead shells providing a suitable substrate for the settling and growth of spat. This is an example of what Kidwell and Jablonski (1983) called taphonomic feedback.

The *Exogyra* lineage has proven useful as a biostratigraphic tool (Stephenson et al., 1942; Richards et al., 1958). *E. ponderosa* is a zone fossil for the Marshalltown Formation in New Jersey, the Black Creek Formation of North Carolina, and the Taylor Formation of Texas; these units are late Campanian in age. *E. costata* zones the Maastrichtian units in New Jersey (the Monmouth Group). At its base is the *E. cancellata* zone, associated with the Mount Laurel Formation and the Campanian-Maastrichtian boundary.

Typical Upper Cretaceous oyster banks are characterized by high-density concentrations of shells (up to 12 valves per cubic decimeter). These "gryph-shaped" shells are thought to be adaptations to soft substrates in deeper shelf waters; they can be categorized as semi-infaunal recliners, with the more convex left valve buried in the mud and the more flattened right valve positioned at or just below the sediment-water interface. By analogy with modern gryphaeids, Cretaceous forms are thought to have been non-incubatory, releasing large numbers of gametes to be fertilized in the water. Resultant larvae drifted in the plankton for an extended period of time (Hopkins, 1979). Modern oyster larvae undergo a series of planktonic developmental stages (see Fig. 6) before settling on suitable substrate as spat.

LaBarbera (1981) performed an interesting experiment in which he dispersed models of *Pycnodonte* and *Exogyra* in the western Gulf Coast of Florida. When he recovered his models, many of the artificial shells showed evidence of attack

Table 2. Benthic faunal analysis—Navesink Formation, Inversand pit, Sewell, N.J.

Taxon	infaunal	semi-infaunal	epifaunal	recliner	suspension feeder	boring
Exogyra		x			x	
Choristothyris			x		x	
Pycnodonte		x		x	x	
Graphaeostrea		x		x	x	
Cucullaea	x				x	
Trigonia	x				x	
Crassatella	x				x	
Liopistha	x				x	
Spondylus (= *Dianchora*) *echinata*			x		x	
Pachycardium	x				x	
Agerostrea		x			x	
Solyma	x				x	
Lithophaga	x				x	
Cliona	x				x	x
Turitella	x				x	x
Total	9	4	2			

Table 3. Benthic faunal analysis—Lower Hornerstown Formation, Inversand pit, Sewell, N.J.

Taxon	infaunal	semi-infaunal	epifaunal	recliner	suspension feeder	boring
Terebratulina			x		x	
Cardium	x				x	
Pycnodonte		x		x	x	
Graphaeostrea		x		x		
Panopea	x				x	
Glycymeris			x		x	
Gervillia (= *Gervilliopsis*)	x				x	
Veniella	x				x	
Crassatella	x				x	
Cucullaea	x				x	
Lithophaga	x					x
Nuculana	x					x
Etea	x				x	
Xylophagella (borer)	x				x	
Total	10	2	2			

Table 4. Benthic faunal analysis—Upper Hornerstown Formation, Inversand pit, Sewell, N.J.

Taxon	infaunal	semi-infaunal	epifaunal	recliner	suspension feeder	boring
Peronidella			x		x	
Flabellum			x		x	x
Terebratulina			x		x	
Cucullaea	x				x	
Ostrea		x			x	
Crassatella	x				x	
Pitar (= *Caryatis*)	x				x	
Total	3	1	3			

by decapod crustaceans; some broken shells were moved 3 to 4 meters away from their original implantation site. The activity of bioturbators also played an important part in moving and changing the orientation of the models. LaBarbera concluded that a combination of increased bioturbation at the end of the Cretaceous, as suggested by Thayer (1979, 1983), and the appearance and spread of efficient duraphagous predators, as hypothesized by Vermeij (1977) were the effective agents that caused the decline and extinction of the abundant Cretaceous semi-infaunal recliners.

An additional factor may have played a part. Evidence of the boring sponge *Cliona cretacica* Fenton and Fenton is observable on many *Exogyra* and *Pycnodonte* specimens from the coastal plain deposits. Over 50% of *E. costata* left valves in the collection of the New Jersey State Museum exhibit sponge boring damage (N = 36). Today, the genus *Cliona* is found inhabiting dead and living oyster shells along the Atlantic continental shelf and in the Gulf of Mexico in subtidal environments down to depths of 30 meters; the yellow sponge riddles the shell with its tunneling and is considered a major pest on oyster beds (Gosner, 1978). While it is not a true parasite, *Cliona* can burrow a shell so thoroughly that the shell weakens and the mollusk dies. Perhaps *Cliona cretacica* was also a contributing factor in the demise of the Cretaceous recliners; by weakening the shell the sponge not only helped destroy the oyster directly, but also made the mollusks more susceptible to duraphagous predators. Hybodont sharks, batoids, shell-crushing osteichthyans, crustaceans and naticid gastropods are all found in association with this oyster-bank ecosystem (Gallagher, 1984; Gallagher et al., 1986).

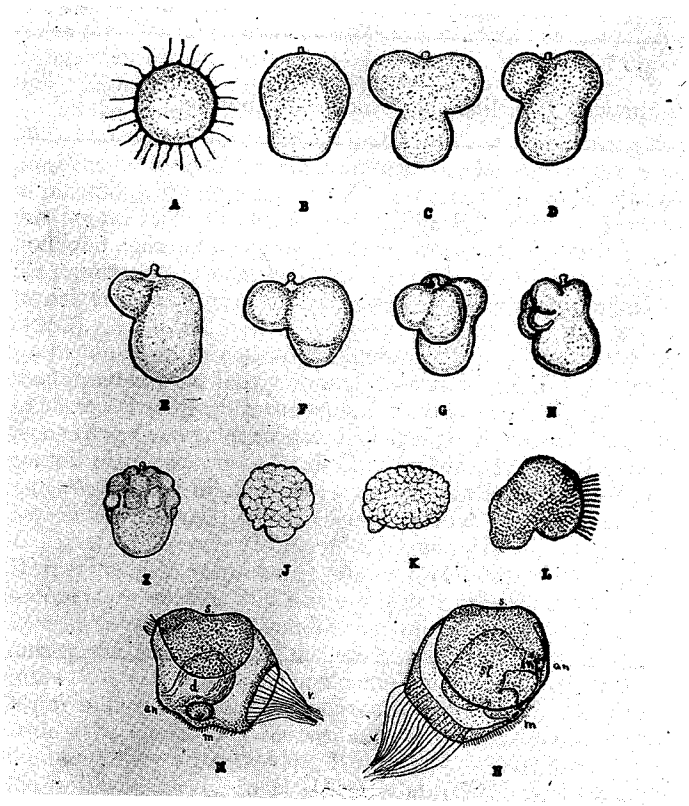


Figure 6. Planktonic larval development stages of the modern oyster, *Crassostrea virginica* (after Nelson, 1941, p. 19).

The greatest concentrations of gryphaeids are found in the Marshalltown, Mount Laurel and Navesink Formations (see Table 2); their numbers decrease in the Redbank and Tinton Formations and their deeper-water equivalent, the New Egypt. At the Inversand Pit (Section 16), their numbers undergo a gradual lessening upward in the Navesink (New Egypt of Koch and Olsson, 1977). There are no *Exogyra* in the upper part, and they are completely missing from the Hornerstown.

The basal portion of the Hornerstown contains abundant oysters of the species *Pycnodonte dissimilaris.* They are usually single valves or broken, and generally demonstrate extensive structural damage from *Cliona* borings. Their shells are thin and thus good specimens are hard to recover, although they are abundantly observable in outcrop. This semi-infaunal recliner is the most abundant species in the Main Fossiliferous Layer (MFL) of the lower Hornerstown Formation, averaging about 1.5 valves per cubic decimeter in the lower part of the MFL (see Fig. 7).

The next most common species is the infaunal bivalve *Cucullaea vulgaris* Morton. There are approximately 100,000 specimens in the collection of the New Jersey State Museum (NJSM 12978), from the MFL of the Inversand Pit at Sewell, Gloucester County, N.J. These infaunal suspension feeders burrowed shallowly in the soft substrate (Jablonski and Bottjer, 1983). Typically *C. vulgaris* occurs as double-valved entire steinkerns.

The third most abundant species in the lower Hornerstown MFL is *Turritella vertebroides* Morton. This gastropod is also a shallowly burrowing infaunal suspension feeder (Saul,

Figure 7. Main Fossiliferous Layer, basal part of Hornerstown Formation, as seen at the Inversand Pit, Sewell, New Jersey. Geologist's hammer is at the level of the oyster bed; other macrofossils (*Cucullaea*) are weathering out in the layer above the hammer.

1983). Table 3 shows a break-down of the benthos by tier and feeding type for the MFL invertebrates.

The faunal composition changes completely in the upper part of the Hornerstown Formation. There is a "barren zone" between the MFL and the next concentration of fossils in the upper Hornerstown. The two meters above the MFL are devoid of body fossils, with the exception of the very occasional shark tooth. At anywhere from two to three meters above the MFL, clusters or patches of fossils appear. This "layer" is much more diffuse than the MFL. It is dominated, in descending order, by a sponge, *Peronidella dichotoma*, a solitary coral, *Flabellum mortoni*, and a brachiopod, *Terebratulina manasquani*. These are all epifaunal suspension feeders; the previously dominant infaunal and semi-infaunal types are much reduced in numbers and generally dwarfed (for example, the smaller and less numerous *Cucullaea macrodonta*, NJSM 10863). (See Table 4.)

The general trend is clear. There is an overall decrease in diversity from the Navesink to the upper Hornerstown. The decline in diversity as well as in biomass abundance is largely at the expense of the semi-infaunal recliners and the infaunal suspension feeders (see Table 5).

Table 5. Total species diversity across the MFL.

	No. of species
Upper Hornerstown Fm.	14
MFL	63
Navesink Fm.	40

If one continues upward in the section, this trend is accentuated. At the Hornerstown Formation-Vincentown Formation contact the dominant species is unquestionably *Olenothyris harlani*, a brachiopod (Feldman, 1977). Densities of *O. harlani* typically reach hundreds of broken, entire, and articulated valves per cubic decimeter (NJSM 15064) in the uppermost part of the Hornerstown, for example at the Shingle Run locality near New Egypt. Feldman (1977) has statistically demonstrated a trend toward more robust and larger individuals within this population upward in the section. He attributes this to shallowing of the marine environment; in fact the larger specimens are found in the lowermost part of the Vincentown (see Section 18). The variation in shell shapes and sizes could also be attributed to normal variation within the population, sexual dimorphism, or to sorting by current activity as the regression of the lower Vincentown took place (Gallagher, 1984). This layer is referred to as the *Oleneothyris* biostrome because it is traceable from Monmouth County to Delaware and in fact into North Carolina. Several species of bryozoa become abundant at this stratigraphic level. The next most abundant benthic invertebrate is the semi-infaunal recliner, *Pycnodonte dissimilaris*. As an aside, this horizon has produced the guembelitriid foraminiferan *Woodringia hornerstownensis* Olsson, 1958, regarded by Keller (1989; also Benjamini and Keller, 1988) as an opportunistic species characterisitic of early Danian depauperate planktonic faunas.

Moving upward into the Vincentown, a diversity rebound occurred in the limesand facies of the formation. In this facies, the most abundant organism is the branching bryozoan *Coscinopleura digitata*, an epifaunal suspension feeder. There are a wealth of other bryozoa species as well, 85 taxa in all, both branching and encrusting; the closest resemblance is to the bryozoan fauna of the type Danian of Europe (Canu and Bassler, 1933). The very high density of bryozoan remains, the indurated limestone occurring in a restricted, mound-shaped lense (see Section 20) and the associated fauna of anthozoa, ahermatypic corals, echinoids, serpulid annelids, and crinoids all suggest a bryozoan bioherm, similar to those described by Thomsen (1977) and Cuffey (1985a, 1985b). The textural designation of this bryozoan build-up, in Cuffey's terminology, would be rudstone to floatstone. Modern bryozoan reefs are now well known (for instance, in the Bahamas) and Cuffey has demonstrated their long geologic range (1985a).

The abrupt transition from semi-infaunal and infaunal suspension-feeding bivalves during the Maastrichtian to Danian faunas dominated by epifaunal suspension-feeding sponges, brachiopods, bryozoa and corals can be explained as the result of two factors: the planktonic crash at the K/T boundary and a decrease in bioturbation due to a decimation of the infauna.

Table 6. Dominant marine invertebrate species in fossil concentrations, New Jersey K/T stratigraphic interval.

Assemblage	Age	Dominant Species	Percent Megafossils[1]	Reproductive Type
Vincentown lime sand	Thanetian	*Coscinopleura digitata*	81	Nonplanktotroph
Oleneothyris biostrome	Danian	*Oleneothyris harlani*	99	Nonplanktotroph
Middle Hornerstown	Danian	*Peridonella dichotoma*	39	Nonplanktotroph
		Flabellum atlantica	30	Nonplanktotroph
		Terebratulina atlantica	30	Nonplanktotroph
MFL[2]	Maastrichtian	*Pycnodonte dissimilaris*	78	Planktotroph
Navesink shell bed	Maastrichtian	*Pycnodonte convexa*	98	Planktotroph
Marshalltown shell bed	Campanian	*Exogyra ponderosa*	99	Planktotroph

[1]Clasts per cubic decimeter.
[2]Main Fossiliferous Layer, lower Hornerstown Formation.

Those two factors are also linked. While both Cretaceous infauna and Paleocene epifauna depended upon planktonic food resources, the critical difference in the two groups of survivors and non-survivors is the trophic requirements of the larval stage. The typically Cretaceous infaunal bivalves possessed planktotrophic larvae (see Kauffman, 1979, 1975) which would have been drastically affected by a plankton mass extinction event; moreover, the reduction of planktotrophic larvae would itself become part of the negative feedback loop, since the planktonic larval stages of many invertebrates are themselves important trophic resources. The common Danian survivors exhibit a variety of reproductive strategies that are independent of plankton supply. For instance, the lophophorates by and large have lecithotrophic larval stages, limiting their range but also freeing them from dependence on plankton (Scheltema, 1976, 1977; Thayer, 1981; Taylor, 1988). Sponges can reproduce by asexual budding, in effect cloning themselves; they can also regenerate themselves from fragmentary bits (Rigby, 1983). Corals undergo alternation of generations, also reproducing asexually (Buchsbaum et al., 1987).

Thus the principal determinant of survivorship across the K/T boundary among the benthic invertebrates in the New Jersey section seems to have been reproductive strategy (see Table 6). Secondarily, the reduction of planktotrophic infauna stocks would have decreased the rate of bioturbation, making substrate conditions more amenable for epifauna that had been suppressed by the Late Cretaceous radiation of bioturbators (Thayer, 1979, 1983). The primary effect was the differential survival of non-planktotrophs such as sponges, corals, brachiopods and bryozoa, as demonstrated by biomass considerations derived directly from outcrop sections (see Table 6). Similar trends can be seen in the type Danian section around Stevns Klint in Denmark, where bryozoa are the principle component of the limestones and are found forming biohermal masses (Bromley, 1979), and brachiopod diversity actually goes up (Surlyk and Johansen, 1984) from the Maastrichtian level.

Macro-Invertebrate Nektonic Paleoecology and Stratigraphy

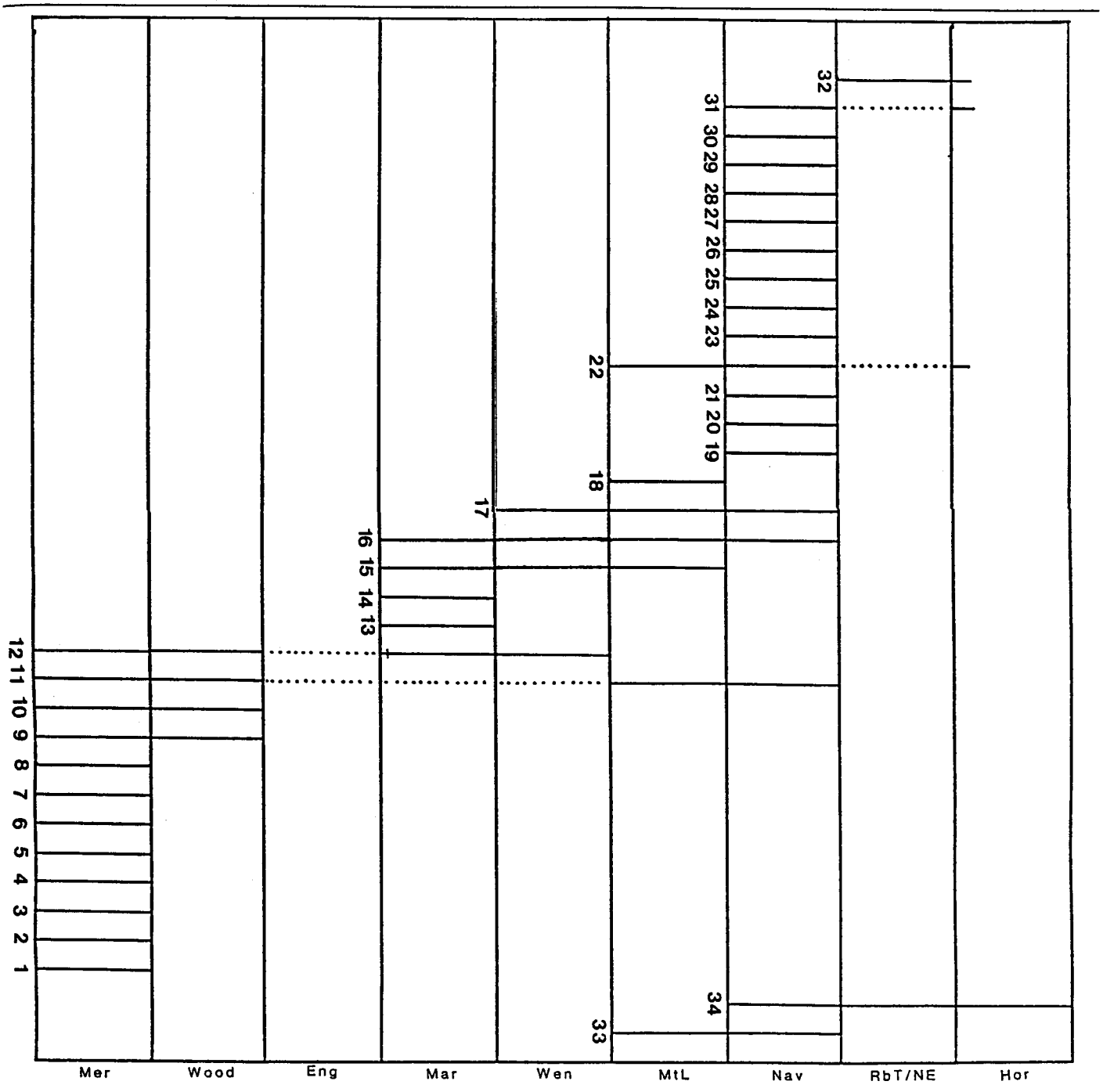
The traditional zone fossils for the marine Upper Cretaceous are the cephalopods, and specifically the ammonites. These macro-invertebrates evolved a wide variety of forms in fairly short intervals of geologic time; being nektonic in habit, they could spread rapidly through the world ocean. Moreover, Saunders and Spinosa (1979) have shown that Recent gas-filled *Nautilus* shells can float up to 1000 km after mortality, and by analogy ammonite shells might have become widely dispersed in the same manner. For these reasons they are perfect biostratigraphic markers. On the other hand, the survival of the long-ranging nautiloids may be instructive in terms of determining selectivity constraints during the K/T mass extinction.

There is a distinct early Campanian suite of ammonites, most of which are found in the Merchantville Formation. These include *Submortonisceras uddeni*, *Submortoniceras vanuxemi*, *Menabites delawarensis*, *Scaphites hippocrepis*, *Scaphites leeii*, *Scaphites similis*, *Baculites* cf. *minerensis*, *Baculites* sp., and *Placenticeras placenta* (see Table 7). *P. placenta* is also found in the Woodbury Formation (for example, near the original *Hadrosaurus foulkii* site in Haddonfield, Camden County, N.J.). No ammonites are found in the regressive sands of the Englishtown Formation.

The Marshalltown Formation has yielded only a few fragmentary remains of ammonites. From Weller's "lost locality" at Swedesboro (see Richards et al., 1958) we have *Placenticeras placenta* and a fragment assigned to *Nostoceras* [*Turrilites*] *pauper* (NJSM 9671). From Marshalltown exposures now largely slumped or covered by riprap along the Chesapeake and Delaware Canal, *Didymoceras* sp., *Anapachydiscus*, and *Parapachydiscus* have been reported (Owens et al., 1970). This fauna is transitional in aspect and is probably middle to late Campanian in age.

The Wenonah Formation around Marlboro has produced a few fragmentary poorly preserved steinkerns tentatively assigned to *P. placenta* (NJSM 9718 and 9719) and *Pachydiscus complexus* (NJSM 10148).

Table 7. Cephalopod biostratigraphy of Upper Cretaceous to Lower Paleocene units in northern Atlantic Coastal Plain.



Range data compiled from Richards et al. (1962), Owens et al. (1970), Cobban (1974), Gallagher et al. (1986), Gallagher (1990a), and New Jersey State Museum collections. **1.** *Baculites asper.* **2.** *Baculites* cf. *minerensis.* **3.** *Menabites* [*Delawarella*] *delawarensis.* **4.** *Submortoniceras uddeni.* **5.** *S. vanuxemi.* **6.** *Scaphites similis.* **7.** *Scaphites* cf. *leeii.* **8.** *Hoploscaphites hippocrepis.* **9.** *Solenoceras annulifer.* **10.** *Baculites* sp. A. **11.** *Baculites ovatus.* **12.** *Placenticeras placenta.* **13.***Parapachydiscus* sp. **14.** *Anapachydiscus* sp. **15.** *Cirroceras* [*Didymoceras*]. **16.** *Nostoceras* [*Turrilites*] *pauper.* **17.** *Pachydiscus* [*Menuites*] *complexus.* **18.** *Anaklinoceras* sp. **19.** *Hoploscaphities pumilis.* **20.** *Hoploscaphites* sp. **21.** *Baculites claviformis.* **22.** *Baculites* sp. B. **23.** *Nostoceras mendryki.* **24.** *Nostoceras* cf. *stantoni.* **25.** *N. hyatti.* **26.** *N. helicinum.* **27.** *Cirroceras* [*Didymoceras*] *navarronense.* **28.** *Axonoceras* cf. *angolanum.* **29.** *Exitoloceras oronense.* **30.** *Sphenodiscus lenticulatus.* **31.** *Pachydiscus* [*Neodesmoceras*]. **32.** *Sphenodiscus lobatus.* **33.** *Belemnitella americana.* **34.** *Eutrephoceras dekayii.*

Formation abbreviations: **Mer**, Merchantville Fm. **Wood**, Woodbury Fm. **Eng**, Englishtown Fm. **Mar**, Marshalltown Fm. **Wen**, Wenonah Fm. **MtL**, Mount Laurel Fm. **Nav**, Navesink Fm. **RbT/NE**, Red Bank, Tinton, and New Egypt Fms. undivided. **Hor**, Hornerstown Fm.

The Upper Campanian-Lower Maastrichtian transition is characterized by the diversification of heteromorph types in the Mount Laurel and Navesink Formations. Significantly, the heteromorph *Anaklinoceras* has been found in Delaware at the Biggs Farm site; this genus marks the top of the Campanian (Lewy, 1986; Eaton, 1987). This ammonite has not been found in New Jersey.

The basal part of the Navesink Formation has yielded a rich ammonite fauna at Atlantic Highlands, Monmouth County, N.J., including *Baculites ovatus*, *B. claviformis*, *Nostoceras helicinum*, *N. hyatti*, *N. pauper*, *Nostoceras* cf. *stantoni*, *N. mendryki*, *Axonoceras* cf. *angolanum*, *Exiteloceras oronense*, *Didymoceras navarronense*, *Hoploscaphites pumilus*, *Hoploscaphites* sp. and *Pachydiscus* sp. (Cobban, 1974). Cobban concluded that this assemblage was stratigraphically near the Campanian-Maastrichtian boundary; in the absence of the diagnostic *Anaklinoceras*, an early Maastrichtian age is preferred here. This determination is supported by age determinations based on the planktonic foraminifera (Olsson, 1963).

The Mount Laurel-Navesink couplet is also characterized by the local abundance of *Belemnitella americana.* The numbers of this belemnite in some beds suggests that these animals lived in large schools, like their modern relative the squid. Belemnites apparently spread across Europe to the British Isles, and thence across the Atlantic to America; they represent a Boreal influence (Reid, 1976). Christensen (1975) believes that *Belemnitella* spread to North America via Greenland and Arctic Canada. *B. americana* is found in the northern Coastal Plain only in the Mount Laurel and Navesink Formations, hence is associated with the Campanian-Maastrichtian boundary. Its highest stratigraphic occurrence in New Jersey is in association with the basal Navesink oyster beds; above this it is exceedingly rare to non-existent. It is, for example, completely absent from the upper Navesink at the Inversand Pit. Thus this form was already missing from the northern Coastal Plain well before the end of Maastrichtian time.

The Upper Maastrichtian assemblage of ammonites is a lower diversity assemblage than the Lower Maastrichtian ammonite fauna, and is composed primarily of *Baculites ovatus*, *Sphenodiscus*, and *Pachydiscus* (*Neodesmoceras*). The last two forms are diagnostic zone fossils for the Maastrichtian (Arkell et al., 1957).

Among the sphenodiscids, *Sphenodiscus lenticularis* occupies a lower stratigraphic position than *S. lobatus. S. lenticularis* is well known from the Severn Formation of Maryland, a middle Maastrichtian unit, where it occurs with *Baculites* sp., *Discoscaphites abyssinius*, *D. conradi*, and *Eutrephoceras dekayi* (Hartstein and Decina, 1986). Bukowski and Bond (1989) have described a specimen of *S. lenticularis* that had been attacked by a predator, probably a mosasaur. This specimen from the Severn Formation, along with previously reported specimens from the Western Interior Cretaceous deposits (Kauffman and Kessling, 1960), raises the possibility that ammonites were unable to hold out against predation by mosasaurs and other recently-evolved efficient duraphagous predators (B. Saunders, personal communication) and so were eaten into extinction. This view is consonant with Vermeij's (1977) hypothesis of a Cretaceous faunal revolution involving the appearance of more effective duraphagous predators. But, while mosasaurs may have taken the occasional ammonite, Martin and Bjork (1987) have shown that some mosasaurs were opportunistic predators capable of preying upon teleost fish, sharks, aquatic birds (*Hesperornis*), and even other mosasaurs.

In New Jersey, *Sphenodiscus lobatus* has been found in the Tinton Formation of late Maastrichtian age at the type section at Tinton Falls, Monmouth County. It is also known from the basal Hornerstown Formation Main Fossiliferous Layer (MFL). Other ammonites found in the MFL include *Baculites ovatus* and *Pachydiscus* (*Neodesmoceras*) sp. In the NJSM Inversand Collection are some 50 lots of ammonites totaling several hundred specimens from the MFL (NJSM 11284, 11321, 11328). While most are fragmentary and worn steinkerns, a few specimens are substantially complete. It would be hard to rework delicately sutured whorls and have them remain intact. The same layer produces mosasaur remains; they and other predators and scavengers may be responsible for breakage of ammonite shells.

Co-occurring with the ammonites in the MFL is the nautiloid *Eutrephoceras dekayii.* The genus *Eutrephoceras* is a long-ranging one, both stratigraphically and spatially; it occurs from the Upper Jurassic to the Miocene, and is cosmopolitan in distribution (Teichert et al., 1964). While found in New Jersey from the Navesink up into the Hornerstown, it is never common (as is *Baculites* in some localities). A fragment (NJSM 10859) from the Upper Hornerstown at the Inversand Pit probably pertains to this species, and demonstrates that in this area this form survived the K/T extinction. The nautiloid lineage is represented in the Lower Eocene Shark River Formation by *Aturia vanuxemi* (NJSM 7802). Table 7 sums up cephalopod biostratigraphy in the coastal plain of New Jersey and Delmarva.

What factor was most important in the differential survival of co-occurring ammonites and nautiloids across the K/T boundary? While mosasaurs may have preyed upon ammonites, this is probably not the only reason for their disappearance. The predator and prey occur together in the MFL; seemingly, both were extirpated in this area at the same time. Presumably, nautiloids would have been equally edible and should have suffered similar predation pressure.

The selective survival factor again appears to be reproductive strategy, as was the case with the benthos. In a study of the early ontogeny of *Eutrephoceras,* Landman et al. (1983) demonstrated that *E. dekayi* produced a few large embryos compared to ammonites, which produce many small embryos. The contrast in embryonic size is attributed to differing fertility and modes of life, yolk-poor ammonite embryos having to spend more time in the plankton, while nautiloid embryos are active swimmers. Emiliani et al. (1981) have cited this difference in habit as the reason for nautiloid survival across the K/T boundary. The more proximal cause of nautiloid survival may be the embryos' larger size with a concomitantly larger yolk store; planktotrophic ammonite embryos of smaller size were probably starved during the plankton crash at the K/T boundary, and other adverse environmental conditions associated with the boundary event contributed to this primary cause for the extinction of the ammonites (Ward, 1983).

This scenario is supported by recent observations of developing *Nautilus* embryos (Arnold and Carlson, 1986). *Nautilus* undergoes rapid development, depending on its large yolk mass for sustenance; it does not experience a larval planktonic stage, but is lecithotrophic, hence it is independent of a planktonic food source.

Still, ammonite diversity seems to have dwindled during the Upper Cretaceous, peaking in the Navesink and dropping off later in the Maastrichtian. Apparently, this happened not only among the northern Coastal Plain ammonites (see Table 7), but also among the group world-wide (Ward and Signor, 1985). Thus the ammonites are another group that demon-

strates a two-stage extinction pattern consisting of a preliminary gradual decline followed by abrupt termination of the remaining stock. It is suggested here that the ammonites offer corroborative evidence for differential extinction dependent on reproductive strategy, the survival of nautiloids confirming the selective survival of non-planktotrophic larval types (Gallagher, 1991).

4. Comparative Taphonomy

A basic problem with range determinations is the possibility of reworking of fossils into younger sediments. This has become a controversial issue in some K/T boundary studies because of the alleged Paleocene dinosaurs found in the uppermost Hell Creek Formation of Montana (Sloan et al., 1986; Rigby, 1987). Some interpretations of the New Jersey K/T section have advocated reworking as an explanation for the Cretaceous fauna found in the basal Hornerstown Formation (Minard et al., 1969); in this view, there is an angular unconformity between the Hornerstown and the subjacent Navesink Formation, a large geologic gap that spans some protracted chronostratigraphic interval including the K/T boundary. But, as Jordan (1976) pointed out, we do not have to assume that every era or period boundary should occur neatly between formations in all places, and the micropaleontological criteria, as we have seen, argues to the contrary.

To address the issue of reworking, we must look to the methods and concepts of taphonomy to provide us with clues to the amount of movement and recycling fossils may have undergone before final burial. I include here case studies of two localities as a way of comparing reworked and non-reworked thanatocoenoses. One site is an estuarine depositional environment with a mixed terrestrial-marine assemblage, while the second site is a marine shelf environment.

Ellisdale, Monmouth County, N.J.
(Section 4, Appendix)

The discovery of the Ellisdale site (see Gallagher et al., 1986, for more details) prompted this author into thinking about the origins of mixed assemblages. This small streambank exposure of the lower Marshalltown Formation (Campanian) yielded a curious admixture of terrestrial plants, terrestrial vertebrates, aquatic/estuarine vertebrates, marine vertebrates and marine invertebrates. Initial streambed collecting of float material eroded out of outcrop and deposited in point bars and lag gravels proved the site to be a promising source of vertebrate fossils. Under the auspices of several National Geographic Society grants (NGS 3299-86, 3842-88, and 3842-88) a team of workers from the New Jersey State Museum participated in the subsequent excavation, prospecting, matrix seiving, taphonomic grid work, screen-washing, and stratigraphic section measurement of the Ellisdale site (Parris et al., 1987). As a result of this work, we have established that most if not all of the fossils are coming out of a small number of thin beds composed of flat pebbles overlain by poorly sorted sand with comminuted lignite (see Section 4). Several of these units are sandwiched closely together near the base of the exposure within a predominantly wavily-bedded thicker clay unit. The specimens are not coming out of the base of this clay layer, which is further downsection. The sorting of the productive units is extremely poor, with grain sizes ranging from silt to large pebbles. The pebbles are generally flattened angular siderite nodules, some of them fluted into shapes that suggest plastic deformation during transport. I interpret the flat pebbles as rip-up clay clasts which were diagenetically indurated. Among other clasts observed in the productive layers are angular pebbles of mica schist, probably derived from the Piedmont metamorphic terrane to the west. In general, the productive horizons are composed of very immature sediments that have the appearance of being "dumped in" (Parris et al., 1987).

These deposits bear very little similarity to the deeper-water Upper Cretaceous units generally characterized by high glauconite content, massive bedding, and more sorted sediment. These glauconitic beds have more dominantly marine assemblages and more complete skeletons than the taphonomically mature mixed assemblage found at Ellisdale. One such glauconitic unit is the Hornerstown Formation, discussed in greater detail below.

The Ellisdale site has produced wood in large quantities; lignified and petrified (sideritized) wood are by far the most common fossils at this locality, and some of the thin sand beds are particularly rich in lignite. Much of the wood is thoroughly riddled by bivalve borings (NJSM 13769); many pieces are highly sculpted, in the manner of driftwood. Plant material also occurs as rounded, flattened pieces, fragments of branches (frequently with knots), crushed conifer twigs with needles, and finely comminuted plant hash.

Although steinkerns of marine bivalves and gastropods are occasionally found at Ellisdale, the principal evidence for marine influence is the bivalve borings in the wood. Hoagland (1983) has shown that several species of modern teredinids experience osmotic stress in salinities below 10 parts per thousand; mortality occurs at 4 parts per thousand. Optimum growth conditions for large populations are above 10 parts per thousand and on this basis we can confidently conclude that the Ellisdale site had estuarine to marine salinity levels. Hall et al. (1978) have stated that modern wood-boring bivalves flourish in subtropical estuaries. The first well-known teredinids are Cretaceous in age; borings in wood from this period can be safely attributed to teredinids (Turner, 1966). Identifiable tubes from Ellisdale have been assigned to the form-taxon *Xylophagella kummeli* (NJSM 13770).

Interestingly enough, many of the reptile bones also exhibit borings (NJSM 12140, 13096, 13779). Frey et al. (1975) found pholadid borings in some of the fossil mammal bones they recovered from modern Georgia estuaries, and Gallagher et al. (1989) have noted the presence of intact pholadids in borings in cetacean bones dredged from the continental shelf. The circular holes in Ellisdale reptile bones resemble pholadid borings more than percussion marks or low-pH dissolution features, although some of the other pitting on these specimens may be attributable to the latter processes. Moreover, a specimen of a hard-substrate borer (*Lithophaga* sp., NJSM 12721) has been found at Ellisdale. The transport of bone and wood into the estuarine environment provided boring organisms with a suitable substrate in the appropriate salinity ranges for nutrient supply, spatial heterogeneity, and trophic resources; this population at Ellisdale represents another facet of the phenomenon labeled "taphonomic feedback" by Kidwell and Jablonski (1983).

The larger stratigraphic setting of the Ellisdale section is instructive. The underlying unit is the Englishtown Formation, a regressive fluvial sand, while the overlying bed is the massive glauconitic silty sand of the transgressive Marshalltown Formation (see Parris et al., 1987, for detailed stratigraphic sections). The poorly sorted flat-pebble horizons in dark clays with cross-bedded sands above constitute a unique transitional unit between a terrestrial regressive unit and fully marine transgressive lithology; moreover, this sort

of lithology can be seen in other areas along strike. Its position between a terrestrial unit and a marine stratum argues for an estuarine origin. Along a passive continental margin undergoing submergence, such a depositional environment could be logically expected. In a study of heavy minerals in the Englishtown, Reed (1960) recognized the estuarine nature of some of the clay beds overlying the characteristic quartz sand lithology of the typical Englishtown.

A persuasive argument for the Ellisdale Member's estuarine origins is the nature of the fossil mix found in these beds. Besides the bored lignitized and permineralized wood, there are numerous shark teeth, ray teeth, teleost remains, amphibian vertebrae, turtle remains of both fresh-water and marine types, lizard specimens, and alligator, crocodile, and dinosaur bones and teeth (see Fig. 8). The bones, with the exception of some of the turtle shell material, tend to occur as disassociated shards or pieces. The taphonomically mature aspect of the remains is enhanced by their abraded and generally worn appearance. Some of the teeth, for example specimens identified as *Dryptosaurus* (NJSM 12436, 14158) are stripped of their enamel, suggesting passage through a digestive tract (Fisher, 1981). Some gar scales are also missing their enamel (Parris et al., 1987).

Another intriguing aspect of the Ellisdale fauna is the occurrence of juvenile forms. The fragmentary hadrosaur teeth recovered from excavations are the shed teeth of juveniles (J. Horner, personal communication). Teeth of the goblin shark *Scapanorhyncus texanus* represent a wide range of sizes. Some of the turtle and crocodile material is diminutive, suggesting immature individuals. The Ellisdale site has proven itself to be a prolific producer of microvertebrates in general (Parris and Grandstaff, 1989; Grandstaff and Parris, 1989).

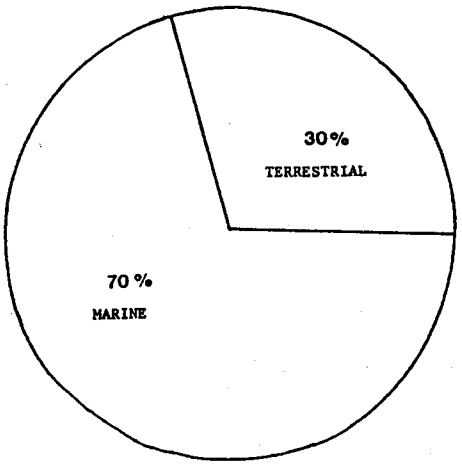


Figure 8. Pie chart showing division of the Ellisdale fauna according to environment.

To summarize, the evidence for an estuarine lagoonal-tidal channel-barrier complex includes six observations:

1. The predominance of wavily-bedded dark organic clays with intercalated thin irregularly bedded cross-stratified sands. Individual sedimentary units are laterally discontinuous lenses that can disappear from a specific section from year to year due to erosion. This gives the impression of a dynamic depositional environment with rapid small-scale sedimentologic changes occurring in a restricted area. Such an environment is the estuarine barrier island-tidal channel-lagoon-embayment complex (Gallagher, 1986b).

2. Specific sedimentary structures such as the clay-sand cross-sets at the top of the Quarry B section (see Section 4B in appendix, and Parris et al., 1987) are indicative of meandering estuarine deposition (Land and Hoyt, 1966; Dodson, 1971). This type of flaser bedding is generally regarded as evidence of a tidal environment (Tucker, 1982).

3. Large quantities of plant material. Today coastal lands adjacent to estuaries are sites of high biomass productivity (Odum, 1963), and terrestrial vegetation is trapped in bays and lagoons and contributes to the high organic content of the sediments deposited in these areas. Paralic sediments found elsewhere in the Cretaceous system are characterized by large quantities of terrestrially-derived plant matter (Retallack and Dilcher, 1981; Gallagher and Johnson, 1986).

4. General stratigraphic context. The Ellisdale Local Fauna is situated between a regressive sand (the Englishtown Formation) and a transgressive glauconitic unit (the classic Marshalltown greensand). Thus the Ellisdale member represents a transitional environment between terrestrial-fluvial deposition and full marine conditions.

5. Admixture of terrestrial, aquatic, estuarine and marine faunas in the Ellisdale member (see Fig. 8). Frey et al. (1975) have shown that such mixtures are presently occurring in modern estuaries. C. S. Churcher (personal communication) suggests that faunal mixing is taking place in Chesapeake Bay today, while Behrensmeyer (1984) has suggested that prehistoric faunal mixes such as those found at Calvert Cliffs, Maryland, and Shark Tooth Hill, California, occurred in estuaries and along beaches; she characterizes these mixes as having "a long and complex taphonomic history" (p. 560).

6. Presence of wood and bone-boring bivalves. Today such organisms (boring mytilid and pholadid clams) are restricted to marine and estuarine environments.

I have proposed elsewhere (Gallagher and Parris, 1986; Gallagher et al., 1986; Parris et al., 1987; Gallagher, 1989b) that the mechanism for concentration of terrestrial, aquatic and marine remains in estuarine and nearshore deposits may involve transportation and mixing of organic remains during peak flow conditions associated with high energy events such as coastal storms. We know that seasonal storm events such as nor'easterers, hurricanes or monsoons are major sediment movers that can also concentrate organic remains in the marine realm (Aigner, 1981; Brett et al., 1986).

Associated peak flow conditions would also facilitate the reworking of organic remains and transport eroded clasts of various ages into the estuarine environment, where contemporaneous fauna and flora of diverse environmental origin may also be admixed as a result of storm-induced mass mortality. Gradient current traction may be a factor in producing mixed assemblages in the nearshore marine area, where littoral erosion, coastal fauna mortality and enhanced compensatory near-bottom flow are all maximized during storms. In the storm depositional model, we have an effective and comprehensive agent for reworking, high-competence transport energy, mass mortality, mixing, quick sedimentation and burial in coastal environments (see Fig. 9).

Evidence for seasonal storm events can be seen in the deposits at Ellisdale. Rapid alternation of thicker clays with thin sand beds containing clay rip-up clasts is suggestive of periodic high-energy events. Dodson (1971) has cited growth rings in wood and champsosaur vertebrae as evidence for seasonality in the Campanian at Dinosaur Provincial Park, Alberta; both wood and reptile bone from Ellisdale also display growth rings. Since most workers consider the Late

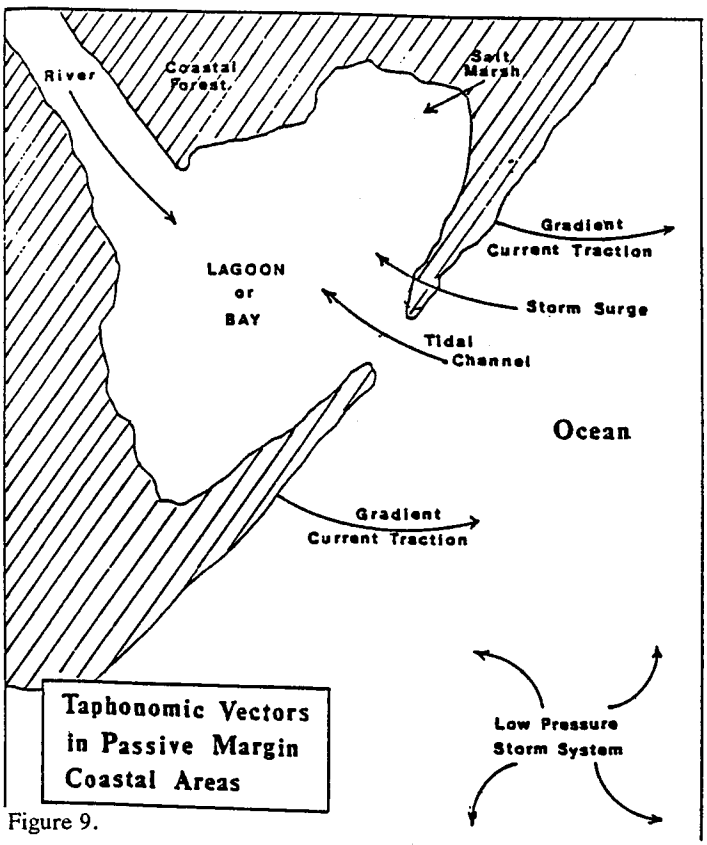


Figure 9.

Cretaceous as a time of generally equable climate the most likely seasonal mode was probably variation in precipitation, rather than temperature change. Further evidence for storm events is the occurrence of charcoal, found in situ in the flat-pebble beds (Parris et al., 1987); this suggests wildfires triggered by lightning.

Frey et al. (1975) found mixtures of terrestrial, estuarine and marine skeletal parts ranging in age from Miocene to Holocene in modern Georgia estuaries. They concluded that Georgia estuaries are better fossil sites than the majority of inland outcrops, that faunal mixing of this sort is a normal estuarine process, and that deposits of this kind are far more widespread in the geologic record than previously suspected. Frey et al. suggested that the evidence for mixed faunas of estuarine origin should be sought in ancient deposits.

The Ellisdale estuarine deposit shows interesting resemblances to the Phoebus Landing site near Elizabethtown, Bladen County, North Carolina. This locality provided E. D. Cope with his type specimen of *Hypsibema crassicauda* (now thought to be a hadrosaur; Parris et al., 1988) and has continued to produce a mixed fauna of Campanian age (Miller, 1967; Baird and Horner, 1979; Robb, 1989). Moreover, a number of sites of varying age demonstrate a similar faunal mix (Gallagher et al., 1986). In addition to the Campanian of New Jersey and North Carolina, the Calvert Formation (Barstovian) of the Chesapeake Bay area and some portions of the Bone Valley Formation (Hemphillian) of Florida contain mixed assemblages. Some continental shelf concentrations of Pleistocene vertebrates may be due to storm processes in estuarine and coastal areas (Gallagher et al., 1989). Bishop (1980) describes a lagoonal-bay bar Pliocene site, Langebaan-weg in South Africa, where fossil bone is concentrated. As a general principal, transgressive phases are optimum times for mixed assemblage deposition. Mixed scrap faunas are a pheonomenon restricted to the later Phanerozoic; they became possible in the Mesozoic and Cenozoic, when large terrestrial vertebrates became relatively common, and when passive continental margins were widespread due to the break-up of Pangaea (Gallagher and Parris, 1986; Gallagher et al., 1986).

Dodson (1980, p. 632) has suggested that ". . . at the appropriate level of generality, taphonomic features will be seen to transcend accidents of time and space." I have offered here a general hypothesis for concentrations of reworked fossils in estuarine and nearshore depositional environments, with diagnostic characteristics of association, sedimentary features, and high taphonomic maturity. The fossils at Ellisdale are unquestionably reworked; now let us look at an assemblage that some workers believe to be reworked, and see how it compares to the Ellisdale taphocoenosis.

Inversand Pit, Sewell, Gloucester County, N.J.
(Section 16, Appendix)

In recent years, much of the discussion about the K/T boundary in New Jersey has centered on the Inversand Company Pit near Sewell in Mantua Township, Gloucester County, N.J. As noted above, various workers (Minard et al., 1969) have favored an angular unconformity at the interface between the Navesink (New Egypt) and Hornerstown Formations at this site; their reasoning is based on the lithological changes observed along strike from the Monmouth County exposures in the northeast, and to the lack of the Navesink Formation outcrop in the Chesapeake and Delaware Canal in Delaware in the southwest (Minard, 1969; Minard et al., 1969; Owens et al., 1970). The latter part of their argument is actually a "straw man," since extrapolation of the strike of the Navesink across the Delaware River into Delaware shows that it would trend south of the C & D Canal area, and so should not be expected to occur there. As Olsson has argued, the lithological changes under the Hornerstown along strike can be explained as facies changes, especially when the same suites of late Maastrichtian planktonic microfossils are present in the underlying units and in the lower Hornerstown (Olsson, 1963; Jordan, 1963; Koch and Olsson, 1977). Another possibility is the condensation of the section along strike, an alternative which will be discussed in the conclusions.

Minard et al. (1969) based their biostratigraphic interpretation on a desultory list of a few species. Subsequent protracted collecting programs by the Academy of Natural Sciences (Richards and Gallagher, 1974) and the New Jersey State Museum (Gallagher and Parris, 1985; Gallagher et al., 1986; Olson and Parris, 1987) have greatly expanded the number of species known from the Inversand Pit, and careful quarrying has produced stratigraphic control on the ranges of species in this critical interval. This is something that many of the earlier workers did not establish.

Moreover, only within the past few decades have taphonomic studies become widespread, and no studies to date have addressed the taphonomy of this important site, the last remaining marl mining operation.

The depositional environments represented at the Inversand Pit range from the inner shelf Navesink clayey glauconitic sand with small quartz pebbles through the deeper water Hornerstown greensand, to the nearshore sands of the Vincentown and Kirkwood formations, overlain by the glacial outwash gravels of the Pleistocene Pensauken Formation (see

Figure 10. Stratigraphic section at Inversand Pit, Sewell, New Jersey. The first cliff up from the bottom of the pit is composed mostly of Navesink Formation; the second cliff (behind the vehicle) is the Hornerstown Formation; the third cliff (uppermost) contains Vincentown, Kirkwood, and Pensauken Formations. Approximate level of the K/T boundary is just below the wheels of the vehicle.

Fig. 10 and Section 16). The Hornerstown Formation is an unusual lithologic unit in that it is composed of greensand, a concentrated form of glauconite. From the data synthesized in recent reviews (Van Houten and Purucker, 1984; Spolijaric, 1986), it appears that glauconite deposition occurs as a replacement of clay minerals and/or organic materials which have been biologically processed through the gut of deposit feeders or clay-particle suspension feeders into fecal pellets which are then altered by precipitations of iron-rich compounds, reworked by bioturbation, and diagentically changed through chemical interactions with seawater. Extensive horizontal burrows, too dense for accurate burrow counts, characterize the lower part of the Hornerstown, lending credence to the biological component of this explanation of glauconite genesis, and fitting in with Seilacher's scheme (1967). Glauconitic deposition is favored in mildly reducing conditions on the sea-floor in mid- to outer continental shelf environments during transgressive phases associated with upwelling of cold water and low rates of terrigeno-clastic sedimentation. Van Houten and Purucker (1984) have speculated that widespread glauconitic deposition around the K/T boundary may have implications for boundary events.

The Navesink Formation at the Inversand Pit, and in all the exposures in the southern portion of the state, is different in lithology from the Navesink Formation at Atlantic Highlands and other localities to the northeast in Monmouth County. At Atlantic Highlands the Navesink is a purer glauconitic sand with fewer quartz pebbles and less clay; at the Inversand Pit, Blackwood Terrace, Mullica Hill and other sites in the southwest it is a clayey glauconitic sand with small quartz pebbles. Trace fossils are primarily vertical burrows, consistent with Seilacher's (1967) conclusion that vertical burrows are characterisitic of nearshore environments. The body fossil assemblage is mostly marine, but there is a significant terrestrial component in the form of large pieces of lignified wood (sometimes log-sized, and occasionally branched [ANSP Paleobotany Collection, 4436]), and dinosaur remains (Colbert, 1948; Gallagher et al., 1986). Portions of skeletons with bones associated and relatively intact are the common taphonomic mode; the excellent *Mosasaurus maximus* skull with articulated cervical vertebrate (NJSM 11053) is an example of this sort of occurrence. Invertebrates are dominated by the oysters, which are densest lower in the section and decrease in numbers upward. Lower down, about 3 meters below the Navesink-Hornerstown contact, the oyster assemblage is a typical Navesink oyster bed, with high concentrations of *Exogyra costata* and *Pycnodonte convexa*, usually as single valves, sometimes as complete double valves. Higher in the section, the larger oysters become less abundant and clumps and clusters of the smaller gregarious *Agerostrea mesenterica,* usually occurring as double-valved complete individuals, are more common. The taphonomic mix is not as terrestrially influenced as the Ellisdale assemblage, and is best described as an inner continental shelf depositional environment with a fully marine fauna that experienced periodic terrestrial input from "bloat-and-float" carcasses and drifting teredinid-riddled logs.

The Hornerstown Formation, by contrast, is remarkably consistent in lithologic character along strike from Monmouth County to Delaware (Minard et al., 1969; Jordan, 1976). It also contains a concentration of fossils in the lower part of its section which is consistently present along strike in New Jersey from Monmouth County to Salem County. This assemblage contains specimens which, because of their taphonomic mode, argue very strongly against any protracted history of reworking.

The most common vertebrate remains in this basal layer, designated the Main Fossiliferous Layer (MFL) by New Jersey State Museum workers, are chondrichthyan, chelonian and crocodilian, in that order. The chondrichthyans are primarily represented by dissociated teeth and calcified vertebrae of sharks (sometimes found semi-articulated or associated, as was the case for NJSM 15150); other elements of the skeleton are missing because, of course, they are composed of cartilage. The other abundant chondrichthyan found at this horizon is the chimaeroid *Ischyodus* [*Edaphodon*]

mirificus. Again, these remains consist of jaw elements and little else, but frequently paired jaw elements belonging to one individual are found closely associated (NJSM 12390-1, 11362-6, 12319-5). Also found are dorsal fin spines (NJSM 12336).

Among the osteichthyans, probably the most significant remains are those of *Enchodus ferox*, usually consisting of teeth or jaw sections with the distinctive palatine fang intact, but with other elements occasionally found as well. *Enchodus* is strictly a Cretaceous form, and no specimens of it are known from the Paleocene (D. Russell, personal communication; Carroll, 1987). Other osteichthyans known from this layer include *Paralbula*, another characteristically Cretaceous genus, and the sturgeon *Acipenser* cf. *albertensis* (NJSM 12805, 12807, 12324).

Chelonian remains are the most abundant reptilian fossils in the MFL. The most common preservation mode is of entire or partial specimens. Frequently the shell plates when found are "shingled" (Baird, 1964; Gaffney, 1975); the individual plates are moved over each other to a certain extent, so that some overlap occurs. The turtle remains are often found in close association with certain invertebrates (notably *Cucullaea vulgaris*, *Turritella vertebroides*, and *Anchura abrupta*; for example, NJSM 14260) or fish remains (chondrichthyan and osteichthyan; for example, NJSM 12360, 12361, 12375). It may be that these remains served as trophic "islands," where scavengers, algal grazers and mobile infauna congregated to take advantage of the food resources generated by carcasses. Sometimes, turtle shells will have associated limb elements (NJSM 12350, 14260), girdle elements (NJSM 12342, 12387), or skull material (NJSM 11051, 11872, 12295; Gaffney, 1975; Fastovsky, 1985; Baird, 1964).

Some turtle shell exhibits pitting or scratch marks possibly caused by scavenging or algal grazing. Usually the pitting is only on one side of the shell plates (NJSM 14260).

The crocodilians are similarly found in partial or whole form, although isolated scutes and teeth are also known from the MFL. Partial skeletons are certainly more common, but the delicate and fragile nature of some of the smaller crocodilians (for example, NJSM 11902, *Diplocynodon* sp., or NJSM 11886, *Procaimanoidea* sp.) would seem to preclude reworking.

Most of the mosasaur material known from the MFL is dissociated, frequently worn-looking vertebrae (NJSM 12627, 12809, 13423, 14160) but teeth (NJSM 11332, *Mosasaurus maximus*; NJSM 11070, *Plioplatecarpus depressus*) and brain cases (NJSM 12184, 11895, *Mosasaurus* sp.) are also found. In all, there are 208 individual pieces of mosasaur from the MFL in the NJSM collection; the ANSP collections from the nineteenth century marl pits contain many more specimens of mosasaur material which may be from this same horizon, but unfortunately precise stratigraphic information is lacking for many of these specimens. The same statement is true for the extensive collection of New Jersey mosasaurs in AMNH.

Perhaps the most unusual and rare specimens from the MFL are the bird remains. Baird (1967) first pointed out the Cretaceous age of many of the birds originally obtained and named by Marsh from the greensands of New Jersey. This observation has been updated by the work of Olson and Parris (1987), a complete review of older specimens and description of some new material obtained from the Inversand Pit MFL. There appear to be 9 or 10 species, mostly of the form-family Graculavidae. Most interesting from a taphonomic standpoint is NJSM 11302, a distal end of the left humerus of a graculavid found conjoined to the associated proximal portions of the radial and ulnar shafts. This is essentially an articulated bird wing of Cretaceous age, a specimen which would be very difficult to rework intact.

Aside from these volant forms, the only terrestrial input in the MFL is the occasional small piece of bivalve-bored wood, and rare pieces of amber (NJSM 14156, 14157, 14739). No dinosaurs or other terrestrial reptiles are known from the MFL; whether this is because dinosaurs were extinct before the deposition of the MFL or because of the deeper-water environment of the Hornerstown Formation cannot be determined. Fig. 11 contrasts the MFL faunal breakdown by environment.

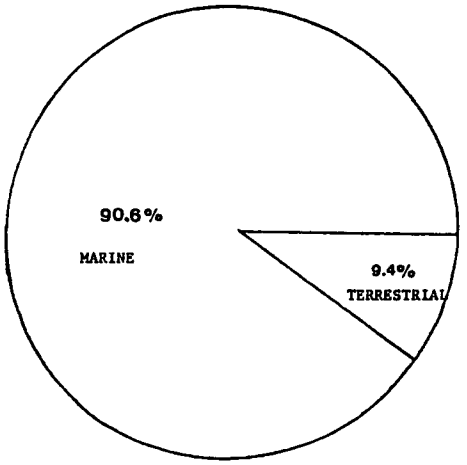


Figure 11. Pie chart showing division of the MFL fauna according to environment.

Taphonomic Analysis

The mixed terrestrial-aquatic marine assemblage at Ellisdale is unquestionably reworked. This taphocoenosis contains remains of animals that could not possibly have lived together (i.e., sharks and dinosaurs). Moreover, all of the specimens obtained from this locality so far have been disarticulated or fragmentary bones and teeth (see Table 8).

Table 8. Comparison of multi-element specimens from Ellisdale and Inversand MFL (in NJSM collections)

	Ellisdale	MFL
Turtles	1	52
Crocodiles	0	38

The MFL at Inversand, however, frequently produces whole or partially articulated specimens. A useful comparison group between the two localities is the turtles. Chelonian remains at Ellisdale are usually broken fragments of shell, just a single bone; sometimes several associated carapace or plastron bones are found, but an entire shell has yet to be excavated from Ellisdale. By contrast, the Inversand Pit is famous for its well-preserved virtually complete chelonian fossils (Baird, 1964; Gaffney, 1975; Fastovsky, 1985; Gallagher et al., 1986).

Clearly the fossil concentrations at these two sites are the products of fundamentally different processes. As shown above, there is abundant evidence for peak-flow deposition of

the Ellisdale assemblage as a result of Late Campanian storm events. A complex taphonomic history for this assemblage is indicated by the advanced degree of bone weathering displayed by the cracking, fracturing and the extensive stripping of exterior compactum; by the stripping of enamel from some teeth and the abundance of coprolites, suggesting the incorporation of a reworked coprocoenosis (as conceptualized by Mellett, 1974), perhaps of crocodilian and shark origin; by the size sorting, with a range of sizes from microvertebrate teeth to large sections of long bone shaft and lignitic logs; and the frequent evidence of bone and wood modification, including extensive riddling of bone and wood by boring organisms. Mixing probably took place in an estuarine setting, possibly a bay receiving reworked bone and floating wood from the terrestrial drainage system and an estuarine and marine component from the seaward side of the bay mouth (see Fig. 9 for a generalized example of such a passive-margin coastal area). Other places where estuarine settings have been studied include Alberta (Koster, 1986) and Georgia (Frey et al., 1975). In both these settings, tidally-dominated environments have proven paleontologically productive.

The Hornerstown MFL represents a very different taphonomic mode; very slow deposition of pure glauconite in mid- to outer shelf environments, with gradual accumulation of organic remains that are comparatively little disturbed. Some reworking of MFL fossils may have occurred, but the principal mode of hardpart modification was primarily biological rather than physical in nature. Scavenging probably played an important part in dissociating some vertebrate specimens; associated invertebrate bioturbation by infaunal suspension feeders (*Cucullaea*, *Turritella*) seeking trophic "islands" may have also helped settle shells and skeletons. In this instance, reworking would probably be downward in the section rather than upward from subjacent deposits; Schäfer (1972, pp. 490-491) discusses "actual paleontological" observations of shell settlement through substrate as a result of extensive bioturbation of marine sediments. Bones may also have been moved in this fashion.

This sort of comparison leads to a fundamental generalization; that in shallower onshore and estuarine settings taphonomic processes will be more influenced by physical events (floods, storms, tides, waves) with biological factors playing a secondary role, while in offshore deeper-water environments the principal taphonomic factors will be biological in nature.

5. Systematic Vertebrate Paleontology

Aside from taphonomic considerations, another problem with mass extinction studies (and diversity studies in general) lies in the appropriate systematics of the groups under scrutiny within the stratigraphic interval of interest. This requires up-to-date taxonomy along with accurate stratigraphic placement. As we have seen, many specimens collected by previous workers in the northern Atlantic Coastal Plain do not have adequate stratigraphic data. An additional complicating factor is the presence in the literature of a plethora of names largely promolgated by nineteenth century workers whose systematic standards were somewhat more relaxed than modern taxonomic practices would permit, so that many taxa in the literature are invalid. In addition, synonymy and misidentification also must be taken into account in any attempt at an accurate count of diversity. Uncritical acceptance of suspicious taxonomic assignments can lead to deceptively large divesity figures and inaccurate stratigraphic ranges. An example of such a mistake is the depiction of the range of the Ichthyosauria (for example, in Sepkoski and Hulver, 1985); an entire order of extinct marine repiltes is shown as surviving to the K/T boundary, when in fact Baird (1984) had already demonstrated that this range determination was based on the misidentified scraps of two plesiosaur bones from the Maastrichtian of New Jersey and the Campanian of Saskatchewan. No ichthyosaurs are in fact known from deposits any younger than Cenomanian in North America.

With these caveats in mind, what follows is an attempt to present as accurate a systematic paleontology of the vertebrate fauna of the Upper Cretaceous and Lower Tertiary section of the northern Atlantic Coastal Plain as is presently possible, incorporating all known synonymies and currently determinable stratigraphic ranges. Undoubtedly, this listing will be modified with further study of museum collections and as new discoveries are made. Tables 9 through 26 (*at the end of this section*) present the data collected for this study; they incorporate all valid names within a precise lithostratigraphic framework. Systematic taxonomy follows Carroll (1988), except for the Chondrichthyan section, which is based on the definitive monograph by Cappetta (1987).

Abbreviations:

AMNH	American Museum of Natural History
ANSP	Academy of Natural Sciences of Philadelphia
MAPS	Monmouth Amateur Paleontological Society
NJSM	New Jersey State Museum
PU	Princeton University (now at YPM)
RU	Rutgers University (now at AMNH)
USNM	U.S. National Museum (National Museum of Natural History, Smithsonian Institution)
YPM	Yale Peabody Museum

Chondrichthyans

The taxonomy of the chondrichthyans has been a welter of confusion, largely due to the fact that usually only teeth are preserved, and many of these demonstrate similarity of form due to parallelism (Cappetta, 1987). This has led to oversplitting and incorrect assignments. The report by Fowler (1911) was the last comprehensive treatment of chondrichthyans of Upper Cretaceous and Tertiary age in New Jersey, and its nomenclature is outdated. Moreover, Fowler worked with collections that had only the most general locality data, and little or no stratigraphic information. Miller's (1955) list suffers from many of the same sorts of problems.

Class Chondrichthyes
Subclass Elasmobranchii
Cohort Euselachii
Superfamily Hybodontoidea
Family Hybodtontidae

***Hybodus* sp.** Marshalltown to Mount Laurel Fms., New Jersey and Delaware. Total stratigraphic range: Mid-Triassic to Maastrichtian.

Family Polyacrodontidae

***Lissodon* (= *Lonchidion*) *babulski* Cappetta and Case, 1975.** Marshalltown to Mount Laurel Fms., New Jersey and Delaware. Generic total stratigraphic range: Mid-Triassic to Maastrichtian.

Subcohort NEOSELACHI
Superorder SQUALOMORPHII
Order HEXANCHIFORMES
Suborder HEXANCHOIDEI
Family HEXANCHIDAE

***Hexanchus* sp.** Basal Hornerstown and Mount Laurel Fms. Total stratigraphic range (genus): Upper Jurassic to Recent.

Superorder GALEOMORPHII
Order ORECTOLOBIFORMES
Family GINGLYMOSTOMATIDAE

***Ginglymostoma globidens* Cappetta and Case, 1975.** Marshalltown and Mount Laurel Fms.
***G. obliquum* (Leidy 1877).** Manasquan and Shark River Fms.
Total stratigraphic range: Albian to Recent.

Order LAMNIFORMES
Family ODONTASPIDAE

***Odontaspis* (*Hypotodus*) *aculeatus* (Cappetta and Case, 1975).** Mount Laurel Fm.
***O. samhammeri* Cappetta and Case, 1975.** Marshalltown and Mount Laurel Fms.
***O.* (*Carcharias*) *hardingi* Cappetta and Case, 1975.** Mount Laurel Fm.
***Odontaspis* sp.** Severn Fm. (Maryland).
Total stratigraphic range: Upper Cretaceous to Recent.

***Striatolamna* (*Otodus*) *striata* (Winkler, 1874).** Vincentown Fm. Total stratigraphic range: Thanetian, Upper Paleocene to Upper Eocene.

***Synodontaspis holmdelensis* (Cappetta and Case, 1975).** Marshalltown and Mount Laurel Fms. Total stratigraphic range: Aptian, Lower Cretaceous to Recent.

Family MITSUKURINIDAE

***Scapanorhyncus* (*Lamna*) *texanus* (Roemer, 1849).** Merchantville, Woodbury, Marshalltown, Mount Laurel and Navesink Fms. Total stratigraphic range: Aptian, Lower Cretaceous to Maastrichtian, Upper Cretaceous.

Family LAMNIDAE

***Xiphodolamia ensis* Leidy, 1877.** Manasquan Fm. Total stratigraphic range: Lower to Middle Eocene.

Family CRETOXYRHINIDAE

***Cretodus* (*Plicatolamna*) *borodini* Cappetta and Case, 1975.** Marshalltown and Mount Laurel Fms. Total stratigraphic range: Cenomanian to Maastrichtian, Upper Cretaceous.
***C.* (*P.*) *arcuata* (Woodward, 1894).** Marshalltown, Wenonah, and Mount Laurel Fms. Total stratigraphic range: Cenomanian to Maastrichtian, Upper Cretaceous.

***Cretolamna* (*Lamna*) *appendiculata* (Agassiz, 1843).** Marshalltown, Wenonah and Mount Laurel Fms. and Vincentown Fm. Total stratigraphic range: Albian, Lower Cretaceous to Ypresian, Lower Eocene.

***Cretoxyrhina mantelli* (Agassiz, 1843).** Merchantville Fm. Total stratigraphic range: Cenomanian to Santonian, Upper Cretaceous.

Family OTODONTIDAE

***Otodus obliquus* Agassiz, 1843.** Vincentown, Manasquan and Shark River Fms. Total stratigraphic range: Thanetian, Upper Paleocene to Ypresian, Lower Eocene.

Family ALOPIIDAE

***Paranomotodon* (*Oxyrhina*) cf. *angustidens* (Reuss, 1845).** Marshalltown, Wenonah, and Mount Laurel Fms. Total stratigraphic range: Cenomanian to Campanian, Upper Cretaceous.

Family ANACORACIDAE

***Squalicorax* (*Corax*) *kaupi* (Agassiz, 1843).** Merchantville, Woodbury, Marshalltown, Wenonah and Mount Laurel Fms.
***S.* (*C.*) *pristodontus* (Agassiz, 1843).** Marshalltown, Wenonah, Mount Laurel, Navesink (New Egypt), and lower Hornerstown Fms.
Total stratigraphic range: Albian, Lower Cretaceous to Maastrichtian, Upper Cretaceous.

***Pseudocorax granti* Cappetta and Case, 1975.** Marshalltown Fm. Total stratigraphic range: Turonian to Maastrichtian, Upper Cretaceous.

Superorder BATOMORPHII
Order RAJIFORMES
Suborder RHINOBATOIDEI
Family RHINOBATIDAE

***Rhinobatos casieri* Herman, 1975.** Marshalltown and Mount Laurel Fms. Total stratigraphic range: Aptian, Lower Cretaceous to Recent.

RHINOBATOIDEA *incertae sedis*

***Pseudohypolophus* sp.** (Cappetta and Case, 1975). Marshalltown and Wenonah Fms. Total stratigraphic range: Cenomanian to Campanian, Upper Cretaceous.

Suborder SCLERORHYNCHOIDEI
Family SCLERORHYNCHIDAE

***Ankistrorhynchus major* Cappetta and Case, 1975.** Mount Laurel Fm. Total stratigraphic range: Santonian to Campanian, Upper Cretaceous.

***Ischyrhiza mira* Leidy, 1856.** Merchantville, Marshalltown, Wenonah, Mount Laurel, Navesink, and lower Hornerstown Fms. Total stratigraphic range: Turonian to Maastrichtian, Upper Cretaceous.

?Sclerorhynchus (Woodward 1889). Marshalltown Fm. Total stratigraphic range: Turonian to Campanian, Upper Cretaceous.

Family *incertae sedis*
(RHINOBATOIDEI or SCLERORHYNCHOIDEI)

***Ptychotrygon vermiculata* Cappetta, 1975.** Marshalltown and Mount Laurel Fms.
***P. hooveri* McNulty and Slaughter, 1972.** Marshalltown Fm.
Total stratigraphic range: Cenomanian to Campanian, Upper Cretaceous.

Family PRISTIDAE

***Pristis amblodon* Cope, 1869.** Lower Eocene (Manasquan? or Shark River? Fm.).
***P. lathami* Leidy, 1877.** Lower Eocene (Manasquan? or Shark River? Fm.).
Total stratigraphic range: Ypresian, Lower Eocene to Recent.

Order MYLIOBATOIDEA
Superfamily MYLIOBATOIDEA
Family MYLIOBATIDAE

***Brachyrhizodus wichitaensis* Romer, 1942.** Marshalltown and Mount Laurel Fms. Total stratigraphic range: Campanian to Maastrichtian, Upper Cretaceous.

***Myliobatis jugosus* Leidy, 1877.** Vincentown Fm. Total stratigraphic range: Paleocene to Recent.

Family RHOMBODONTIDAE

***Rhombodus laevis* Cappetta and Case, 1975.** Marshalltown, Wenonah, and Mount Laurel Fms. Total stratigraphic range: Campanian to Maastrichtian, Upper Cretaceous.

Subclass HOLOCEPHALI
Order CHIMAERIFORMES
Suborder CHIMAEROIDEI
Family CHIMAERIDAE

***Edaphodon stenobyrus* (Cope).** Lower Hornerstown Fm.
***E. mirificus* Leidy.** Navesink and lower Hornerstown Fms.
Total stratigraphic range: Lower Cretaceous to Pliocene.

***Ischyodus bifurcatus* Case, 1978.** Merchantville, Woodbury, Mount Laurel, and Navesink Fms.
***Ischyodus* cf. *thurmanni* Pictet and Campiche.** Lower Hornerstown Fm.
Total stratigraphic range: Middle Jurassic to Paleocene.

OSTEICHTHYANS

The record of bony fish in the K/T section of the northern Coastal Plain is somewhat sparse, and there may be more diversity than is currently recognized. For instance, the presence of *Acipenser* and *Atractosteus* in these deposits was only recognized recently, and Lauginiger (1984) noted several unnamed teleost tooth forms in the Campanian of Delaware. Also, there are new reports of coelacanth remains from the Cretaceous of the coastal plain. The list presented here follows Carroll (1988) for systematics and stratigraphic ranges.

Class OSTEICHTHYES
Subclass ACTINOPTERYGII
Infraclass CHONDROSTEI
Order ACIPENSERIFORMES
Suborder ACIPENSEROIDEI

***Acipenser* sp.** Marshalltown and lower Hornerstown Fms. Total stratigraphic range: Upper Cretaceous to Recent.

Infraclass NEOPTERYGII
Order LEPISOSTEIFORMES
Family LEPISOSTIDAE

***Atractosteus* sp.** Marshalltown Fm. (NJSM 14738). Total stratigraphic range: Upper Cretaceous to Recent.

***Lepisosteus* sp.** Marshalltown, Wenonah, and Mount Laurel Fms. Total stratigraphic range: Upper Cretaceous to Recent.

Order PYCNODONTIFORMES
Family PYCNODONTIDAE

***Anomaeodus* (*Pycnodus*) *phaseolus* (Hay).** Merchantville, Marshalltown, Wenonah, Mount Laurel, Navesink, and Severn Fms. Total stratigraphic range: Lower to Upper Cretaceous.

Division TELEOSTEI
Order ICHTHYODECTIFORMES
Family ICHTHYODECTIDAE

***Xiphactinus audax* Leidy.** Marshalltown, Wenonah, Mount Laurel, and Navesink Fms. Total stratigraphic range: Lower to Upper Cretaceous.

Subdivision ELOPOMORPHA
Order ELOPIFORMES
Suborder ALBULIDEI
Family ALBULIDAE

***Albula* sp.** Marshalltown Fm. Total stratigraphic range: Upper Cretaceous to Recent.

Family ?PHYLLODONTIDAE

***Paralbula casei* Estes.** Marshalltown, Wenonah, and Mount Laurel Fms. Total stratigraphic range: Upper Cretaceous to Miocene.

Superorder SCOPELOMORPHA
Order AULOPIFORMES
Suborder ENCHODONTOIDEA
Family ENCHODONTIDAE

***Enchodus ferox* Leidy.** Merchantville, Woodbury, Marshalltown, Wenonah, Mount Laurel, Navesink and lower Hornerstown Fms. Total stratigraphic range: Upper Cretaceous.

Superorder ACANTHOPTERYGII
Order TETRAODONTIFORMES
Suborder BALISTOIDEI
Family TRIGONODONTIDAE

***Stephanodus* sp.** Marshalltown, Wenonah, and Mount Laurel Fms. Total stratigraphic range: Upper Cretaceous to Eocene.

AMPHIBIANS

The first remains of amphibians were only recently reported from New Jersey (Parris et al., 1987) and study continues on these rare microvertebrate novelties (Parris and Grandstaff, 1989).

Class AMPHIBIA
Order URODELA
Suborder PROTEOIDEA
Family BATRACHOSAURIDIDAE

Cf. *Opisthotriton* sp. (NJSM 14207). Marshalltown Fm. Total stratigraphic range: Upper Cretaceous to Upper Paleocene.

Suborder SALAMANDROIDEA

Salamandridae indet. Marshalltown Fm.

Order ANURA
Family PELOBATIDAE

Pelobatidae indet. Marshalltown Fm.
Anura indet. Marshalltown Fm.

Reptiles

The taxonomy of the fossil reptiles from the K/T section of the northern Coastal Plain has been complicated by the practice of assigning names to scrappy specimens. Probably nowhere is the problem of real versus apparent diversity more in evidence than in the systematics of the turtles. For instance, Miller (1955) lists nine species of *Osteopygis* from this section; Zangerl (1953) had already synonymized these into one species, and included several other genera as well, so that where there appeared to have been thirteen different species among five distinct genera there is now known to be one taxon. Other groups suffer more or less from this noise; I have listed here all the invalid names with their valid synonyms and compared diversity figures before and after synonymy (see Table 27).

Table 27. Comparison of invalid and valid K/T reptilian taxa in the northern Atlantic Coastal Plain

Total reptilian taxa	105
Invalid reptilian taxa	61
Valid reptilian taxa	44
Signal/Noise Ratio	42%

I have also included in this section detailed information on localities and repositories of specimens; this is an attempt to produce a complete listing of known specimens. The listing for dinosaurs is especially exhaustive, since many of the sections I measured are historically important dinosaur sites (see Sections 1, 2, 4, 6, 8, 9, 10, 11, and 16 [Appendix]) and I have attempted to place some of these dinosaur specimens in their stratigraphic context (for more information on New Jersey dinosaurs see Gallagher, 1990b). Moreover, this more detailed listing is important since reptile remains in the area under study cannot be considered common, as for example marine invertebrates or chondrichthyans are in places.

Class Reptilia
Subclass Testudinata
Suborder Pleurodira
Family Pelomedusidae

Bothremys

Total stratigraphic range: Upper Cretaceous to Miocene.

***Bothremys cooki* Leidy.** Merchantville Fm., Maple Shade, Burlington Co., N.J. Type: AMNH 2521 (formerly RU 1.KV-6) from Greensand (= Hornerstown Fm.?), Barnsboro, Gloucester Co., N.J. (Leidy, 1865, 110-113).

***B. barberi* (Schmidt).** Basal Marshalltown Fm., Ellisdale, Monmouth Co., N.J., NJSM 12704-12707 (Gallagher et al., 1986).

***Bothremys* sp.** Endocast of skull, Magothy Fm., Cliffwood Beach, Monmouth Co., N.J. (Gaffney, 1977).

Taphrosphys

Total stratigraphic range: Upper Cretaceous to Miocene.

***Taphrosphys (Platemys) sulcatus* Leidy.** Type: AMNH 2522 (formerly RU 1.KV-7) from Greensand (= Hornerstown Fm.?), Tinton Falls, Monmouth Co., N.J. NJSM 11340, 10410, PU 18706-18708 (now at YPM), ANSP 15544 all from MFL, lower Hornerstown Fm., Inversand Pit, Sewell, Gloucester Co., N.J. Synonymized by Gaffney (1975) with:

= *T. leslianus* Cope from Hornerstown Fm., Hornerstown, Monmouth Co., N.J. Type: AMNH 1467.
= *T. longinuchus* Cope from Hornerstown Fm., Medford, Burlington Co., N.J. Type: AMNH 1125.
= *T. molops* Cope from Hornerstown Fm., Barnsboro, Gloucester Co., N.J. Type: AMNH 1472. Also ANSP 9213-9216 from Hornerstown Fm., Permutit Pit, Birmingham (Pemberton), Burlington Co., N.J.; and NJSM 11306, lower Hornerstown Fm., Inversand Pit, Sewell, Gloucester Co., N.J.
= *T. nodosus* Cope from Hornerstown Fm., Hornerstown, Monmouth Co., N.J. Type: AMNH 1480.
= *T. strenuus* Cope from Hornerstown Fm., Barnsboro, Gloucester Co., N.J. Type: AMNH 1126.

Suborder Cryptodira
Superfamily Trionychoidea
Family Dermatemydidae

Adocus

Total stratigraphic range: Upper Cretaceous to Eocene.

***Adocus beatus* Leidy.** From the Greensand (=Hornerstown Fm.?), Mullica Hill, Gloucester Co., N.J. Type: ANSP 9184 (see Leidy, 1865, 107-108). Also known from lower Marshalltown Fm., Ellisdale, Monmouth Co., N.J. (NJSM 12711; Gallagher et al., 1986) and lower Hornerstown Fm., Inversand Pit, Sewell, Gloucester Co., N.J. White (1972) has synonymized the following species with A. beatus:

= *A. agilis* Cope, Hornerstown Fm., Barnsboro, Gloucester Co., N.J. Type: AMNH 1135.
= *A. lacer* Hay, Hornerstown Fm.?, New Jersey. Cotypes: AMNH 1350 and ANSP 9598.
= *A. pravus* Leidy, Greensand (= Hornerstown Fm.?), Tinton Falls, Monmouth Co., N.J. Type: RU 1.KV-9 (now at AMNH).
= *A. punctatus* Marsh, Hornerstown Fm., Hornerstown, Monmouth Co., N.J. Type: YPM 780.
= *A. syntheticus* Cope, Hornerstown Fm., Barnsboro, Gloucester Co., N.J. Type: AMNH 1466.

Agomphus

Total stratigraphic range: Upper Cretaceous to Oligocene.

***Agomphus turgidus* Cope, 1869.** Hornerstown Fm., Mount Holly, Burlington Co., N.J. Type: AMNH 1481. Also ANSP 15359, MFL of Hornerstown Fm. and NJSM 12328 also from MFL, Hornerstown Fm.; both from Inversand Pit, Sewell, Gloucester Co., N.J. YPM from Hornerstown Fm., Hornerstown, Monmouth Co., N.J.

= *A. masulinus* Wieland, 1905, Hornerstown Fm., Barnsboro, Gloucester Co., N.J. Type: YPM 671.
= *A. pectoralis* Cope 1868, Hornerstown Fm., Medford, Burlington Co., N.J. Type: AMNH 1478.
= *A. tardus* Wieland, 1905, Hornerstown Fm., Birmingham, Burlington Co., N.J. Type: YPM 774.
= *Emys firmus* Leidy, 1856, Hornerstown Fm., Tinton Falls, Monmouth Co., N.J. Type: RU 1.K.V.8.

***Agomphus petrosus* Cope, 1868.** Matawan Group (Campanian), Gloucester City, Camden Co., N.J. Type: AMNH 1482.

Family Trionychidae

Trionyx

Total stratigraphic range: Cretaceous to Recent.

***Trionyx halophila* Cope, 1869.** Merchantville Fm.?, Summit Bridge, New Castle County, Delaware. Type: AMNH 1476. Also: ANSP 9198 from Camden Co., N.J. (probably Matawan Group); NJSM 12464 from Marshalltown Fm., Ellisdale, Monmouth Co., N.J.; *Trionyx* sp. from Wenonah-Mt. Laurel Fms., Big Brook, Monmouth Co., N.J. (Lauginiger, 1986); *Trionyx* sp. from Marshalltown Fm., St. Georges spoils, Chesapeake and Delaware Canal, Delaware (Lauginiger, 1984).

Superfamily CHELONIOIDEA
Family PROTOSTEGIDAE

Psneumatoarthrus

***Pneumatoarthrus peloreus* Cope, 1870.** ANSP 9225, formation undetermined, probably Maastrichtian (Baird, 1978); close to *Archelon.*

Atlantochelys

***Atlantochelys mortoni* Agassiz, 1849.** Cretaceous greensand of Burlington Co., N.J., ANSP 9234 (Hay, 1908).

Protostegidae, aff. Protostega

Protostegid neural plate from Mt. Laurel Fm. (Campanian), Hornerstown, Monmouth Co., N.J. (PU 23252, Baird, 1984); close to *Protostega.*

Family TOXOCHELYIDAE

Dollochelys

Total stratigraphic range: Upper Cretaceous to Eocene.

***Dollochelys atlantica* (Zangerl).** Woodbury Fm., Haddonfield, Camden Co., N.J. (Gallagher et al., 1986; NJSM 12757). Type: YPM 625 from Hornerstown Fm., Barnsboro, N.J. NJSM 12295, 12321, 12374, MFL, basal Hornerstown Fm., Inversand Pit, Sewell, N.J.

Osteopygis

All species of *Osteopygis* Cope, 1868, listed by Miller (1955) are *Osteopygis* (*Lytoloma*) *emarginatus* Cope, 1868. Basal Navesink Fm., early Maastrichtian, Atlantic Highlands, N.J., NJSM 12921 (Baird, 1986b); frontal and prefrontal.

***Osteopygis emarginatus* Cope, 1868.** Hornerstown Fm., Barnsboro, Gloucester Co., N.J. Type: AMNH 1344. Hornerstown Fm., Birmingham (Pemberton), Burlington Co., N.J.; AMNH 1133, mandible only. Severn Fm., middle Maastrichtian, Landover, Maryland (Baird, 1986a, b); nuchal, costals. MFL, basal Hornerstown Fm., latest Maastrichtian, Inversand Pit, Sewell, N.J.; NJSM 11872 (Fastovsky, 1985), skull.

= *O. borealis* Wieland, 1904 (*Propleura*), Hornerstown Fm., Hornerstown, N.J. Type: YPM 778.

= *O. chelydrinus* Cope, 1868, Hornerstown Fm., Barnsboro, N.J. Type: AMNH 1131.

= *O. erosus* Cope, 1875, Hornerstown Fm., Barnsboro, N.J. Type: AMNH 1130.

= *O.* (*Erquelinnesia*) *molaria* Hay, 1908, Hornerstown Fm., Birmingham (Pemberton), Burlington Co., N.J. Type: AMNH 9220.

= *O. platylomus* Cope, 1869, probably Hornerstown Fm., Pemberton (from Manasquan?). Type formerly at ANSP, 14676.

= *O. robustus* Hay, 1908, Hornerstown Fm., Birmingham (Pemberton), Burlington Co., N.J. Type: AMNH 2360.

= *O.* (*Chelone*) *sopitus* Leidy, 1865, Navesink Fm., Mullica Hill, Gloucester Co., N.J. Type: ANSP 9223; *nomen vanum*, see Zangerl (1953, p. 207).

Osteopygis sp. Hornerstown Fm., Vincentown, Burlington Co., N.J. ANSP 9221-8. Also: New Jersey, ANSP 9209.

Also includes *Euclastes*, ?*Lytoloma*, ?*Propleura*, and *Rhetechelys* (Carroll, 1988, p. 616), thus this would include Miller's (1955) listing of:

***Rhetechelys platyops* Cope, 1867 (*Euclastes*).** Vincentown Fm., Hurffville, Gloucester Co., N.J. Type: ANSP 10187.

***"Lytoloma" angusta* Cope, 1869-70.** Birmingham (Pemberton), Burlington Co., N.J.; *nomen vanum*, see Zangerl (1953, p. 145). Type: AMNH 1133. Also claimed as *Prionochelys* cf. *nauta* (see below; Baird and Case, 1966).

***"Lytoloma" jeansii*, Cope.** Hornerstown Fm., Barnsboro, Gloucester Co., N.J. Type: missing. Referred specimen AMNH 1473 is a mixed specimen. *Nomen vanum* (Zangerl, 1953, p. 145).

Peretresius

Total stratigraphic range: Upper Cretaceous.

***Peretresius ornatus* (Leidy, 1856).** Mentioned by Leidy (1865, p. 105) as *Chelone ornata* "from the Green-sand of Burlington County, N.J." Miller (1955) lists this type specimen (ANSP 9218) as from the "Burlington Co., Vincentown limestone", although Baird (1964) points out that there is no basis for this assignment. Baird (1964) synonymizes *Taphrophys nodosus* (Cope) with *P. ornatus.*

***P. ornatus* (Leidy).** NJSM 11051 from Navesink Fm., Inversand Pit, Sewell, Gloucester Co., N.J.

***P. ornatus* (Leidy).** MAPS 1203 from Severn Fm., Maryland; also PU 23569, 21709, Navesink Fm. of Atlantic Highlands and Big Brook, both in Monmouth Co., N.J. (both now at YPM; Baird, 1986c).

***Peretresius* cf. *ornatus* (Leidy).** NJSM 13735 from MFL, lower Hornerstown Fm., Inversand Pit, Sewell, Gloucester Co., N.J.

***Taphrosphys nodosus* Cope.** AMNH 1480 type specimen from Hornerstown, Monmouth Co., "18 ft. below the surface of the Chocolate Marl, which lies below the upper bed of green sand" (Cope, 1870, p. 167); Baird (1964) assigns this to the New Egypt (or lower part of Redbank) Fm. and thus it is early Late Maastrichtian in age.

***Taphrosphys nodosus* Cope.** AMNH 1410, "chocolate marl near Barnsboro," Gloucester Co., N.J. This is probably the Navesink (= New Egypt) Fm. Six bones.

Prionochelys

Total stratigraphic range: Upper Cretaceous.

***Prionochelys* cf. *nauta* Zangerl, 1953.** PU 18817 (now at YPM) from Navesink Fm., Novak Farm, Lumberton, Burlington Co., N.J. Also AMNH 1133, type of *Lytoloma angusta* (based on right peripheral) from Birmingham (Pemberton), Burlington Co., N.J., presumably Hornerstown Fm., possibly Navesink Fm.; synonymized by Baird and Case (1966).

Family CHELONIIDAE

Corsochelys

***Corsochelys* sp.** NJSM 14600 from basal Marshalltown Fm., Ellisdale, Monmouth Co., N.J.; and MAPS 1216a, girdle element from basal Navesink Fm., Atlantic Highlands, Monmouth Co., N.J.

Subclass DIAPSIDA
Infraclass LEPIDOSAUROMORPHA
Superorder LEPIDOSAURIA
Order SQUAMATA
Suborder LACERTILIA
Infraorder LEPTOGLOSSA (SCINCOMORPHA)
Family SCINCIDAE

Contogenys

***?Contogenys* sp.** NJSM 14205 from lower Marshalltown Fm., Ellisdale, Monmouth Co., N.J. (Parris et al., 1987).

Infraorder DIPLOGLOSSA (ANGUIMORPHA)
Superfamily ANGUOIDEA
Family ANGUIDAE

?Anguidae indet. NJSM 14209 from lower Marshalltown Fm., Ellisdale, Monmouth Co., N.J. (Parris et al., 1987).

LACERTILIA indet.

NJSM 14210, 14525, 14211, 14599, 14519, 14302, from lower Marshalltown Fm., Ellisdale, Monmouth Co., N.J.

Superfamily VARANOIDEA (PLATYNOTA)
Family MOSASAURIDAE
Subfamily MOSASAURINAE

Clidastes

Total stratigraphic range: Upper Cretaceous.

***Clidastes iguanavus* Cope, 1868.** from Marshalltown Fm., Swedesboro, Gloucester Co., N.J. Type: YPM 1601. This is the only valid species of *Clidastes* recognized by Russell (1967) from New Jersey.

***Clidastes* sp.** ANSP 19642 (isolated tooth) from Merchantville Fm., Maple Shade, Burlington Co., N.J.

Cf. *Clidastes* sp. NJSM 14243 from Marshalltown Fm., Chesapeake and Delaware Canal, New Castle Co., Delaware.

Globidens

Total stratigraphic range: Upper Cretaceous.

***Globidens alabamaensis* Gilmore.** Two isolated teeth in the private collection of Eugene Hartstein; casts of these specimens are deposited under NJSM 12504. From spoil piles near Summit Bridge, Chesapeake and Delaware Canal, New Castle Co., Delaware. Probably from Matawan Group deposits (Campanian; see Gallagher, 1984).

Halisaurus

Total stratigraphic range: Upper Cretaceous.

***Halisaurus* (*Baptosaurus*) *platyspondylus* Marsh 1869.** Navesink (= New Egypt) Fm., Hornerstown, Monmouth Co., N.J. Type: YPM 444. Also PU 18818 (now at YPM) from Navesink Fm., Novak Farm, Lumberton, Gloucester Co., N.J. (Baird and Case, 1966); NJSM 12259 from Navesink (= New Egypt) Fm., Inversand Pit, Sewell, Gloucester Co., N.J.; known also from Navesink Fm., Big Brook, Monmouth Co., N.J. (Bukowski, 1983); Severn Fm., Landover, Maryland; Merchantville Fm., Deep Cut at Summit Bridge, New Castle Co., Delaware; Mount Laurel Fm., Biggs Farm, St. George, New Castle Co., Delaware.

Liodon

Total stratigraphic range: Upper Cretaceous.

***Liodon* (*Tylosaurus*) *sectorius* (Cope, 1871).** Cited "from marl pits of the Pemberton Marl Co. at Birmingham", Burlington Co., N.J., probably Navesink Fm. (Russell, 1967). Type: AMNH 1401. Also ANSP 9669-9670 from Hornerstown Fm.(?), Vincentown, Burlington Co., N.J.

Mosasaurus

Total stratigraphic range: Upper Cretaceous.

***Mosasaurus conodon* (Cope, 1881) (= *Clidastes conodon*).** Navesink Fm., near Freehold, Monmouth Co., N.J. Type: AMNH 1380 (formerly RU 1-KV.11).

= *Clidastes* (*Neoportheus*) *validus* (Cope, 1868). From Hornerstown Fm.(?), Barnsboro, Gloucester Co., N.J. Type: AMNH 1395.

***M. dekayii* Bronn, 1838.** From the "foot of the Neversink Hills, Sandy Hook, Monmouth Co. (New Jersey)"; (Russell, 1967); this is essentially the same locality as Atlantic Highlands, and so it is likely from the Navesink Fm. The type is unavailable; neither Russell nor Miller (1955) could locate it. The type was apparently an isolated tooth (Russell, 1967). Russell synonymizes the following form:

= *M. meirsii* (Marsh, 1869). From Hornerstown Fm.(?), Hornerstown, Monmouth Co., N.J. Type: YPM 443.

***M. maximus* Cope, 1869.** From Navesink Fm., Middletown, Monmouth Co., N.J. Type: AMNH 1389. Russell (1967) synonymizes:

= *M. princeps* Marsh, 1869. Type YPM 430 from Hornerstown Fm., Hornerstown, Monmouth Co., N.J.

= *M. oarthrus* Cope, 1869. Type AMNH 1392 from Hornerstown Fm., Barnsboro, Gloucester Co., N.J.

= *M. fulciatus* Cope, 1869-1870. Type AMNH 1398 from Monmouth Co., N.J.

Also, two complete skulls of *M. maximus* (NJSM 11052 and 11053) are known from the Navesink (= New Egypt) Fm. of the Inversand Pit, Sewell, Gloucester Co., N.J. Several specimens are reported from the Severn Fm. of Maryland by Baird (1986c). NJSM 11332 contains teeth of *M. maximus* from the MFL, lower Hornerstown Fm., Inversand Pit, Sewell, Gloucester Co., N.J.

***Mosasaurus* sp.** Numerous additional specimens referable to this genus but without adequate locality or stratigraphic data are in the collections of AMNH, ANSP, and YPM.

Subfamily PLIOPLATECARPINAE

Plioplatecarpus

***Plioplatecarpus depressus* (Cope, 1868).** Type missing; originally from Birmingham (Pemberton), Burlington Co., N.J. Russell (1967) synonymizes:

= *Mosasaurus copeanus* Marsh, 1869. Type, YPM 312, is from Navesink Fm., Marlboro, Monmouth Co., N.J.

= *Halisaurus* (*Baptosaurus*) *fraternus* Marsh, 1869. Type YPM 445.

Russell (1967) lists the above two synonyms as from "the Maastrichtian greensands of New Jersey" (p. 161), as was probable for the type, which Miller (1955) identifies as coming from the Hornerstown Fm. Russell tentatively includes the type of *Liodon* (*Tylosaurus*) *laticaudus* Marsh, 1870 in his synonymy; this consists of a single broken caudal.

Prognathodon

Total stratigraphic range: Upper Cretaceous.

***Prognathodon rapax* (Hay, 1902).** Type AMNH 1490 from Barnsboro, Gloucester Co., N.J., probably from upper part of Navesink (= New Egypt) Fm.; see Baird (1986a). Russell (1967) synonymizes:

= *Tylosaurus* (*Macrosaurus*) *laevis* Leidy, 1865. From Greensand of New Jersey. Type: ANSP 9632-3.

= *Liodon validus* Cope, 1869-1870. Type AMNH 1395 from Hornerstown Fm., Barnsboro, Gloucester Co., N.J.

= *Ancylocentrum hungerfordi* Chaffee, 1939. Type NJSM 9827 from upper Navesink (= New Egypt) Fm., Inversand Pit, Sewell, Gloucester Co., N.J.

Suborder SERPENTES
Infraorder HENOPHIDA
Superfamily BOOIDEA
Family BOIDAE

Cheilophis

Total stratigraphic range: Paleocene to Eocene.

***Cheilophis huerfanoensis* Gilmore, 1938.** Vincentown, Burlington Co., N.J., from Vincentown Fm., YPM 18625. (Miller, 1955). Thanetian.

Family ?PALEOPHIDAE

Paleophis

Total stratigraphic range: Upper Cretaceous to Middle Eocene.

***Paleophis littoralis* Cope, 1868.** Type AMNH 2392 from Manasquan Fm., Squankum, Monmouth Co., N.J.; three vertebrae. USMN 11753 from Vincentown Fm., Thanetian, Vincentown, Burlington Co., N.J.; single vertebra (Gilmore, 1938). ANSP 8995 from Manasquan Fm., Ypresian, Shark River, Monmouth Co., N.J. (Cope, 1872; Gilmore, 1938).

***P. halidanus* Cope, 1868.** Type YPM 2763 from Manasquan Fm., Ypresian, Squankum, Monmouth Co., N.J.; single vertebra (Cope, 1872; Gilmore, 1938).

***P. grandis* Marsh, 1869.** Type YPM 2762 from Shark River Fm., Lutetian, near Shark River, Monmouth Co., N.J.; single vertebra (Cope, 1872; Gilmore, 1938).

Pterosphenus

Total stratigraphic range: Eocene.

***Pterosphenus* cf. *schucherti* Lucas, 1899.** ANSP 8996 from Vincentown Fm., Thanetian, Vincentown, Burlington Co., N.J. (Miller, 1955; Holman, 1979).

Superorder Sauropterygia
Order Plesiosauria
Superfamily Pliosauroidea
Family Pliosauridae

Cimoliasaurus

Total stratigraphic range: Upper Cretaceous.

***Cimoliasaurus magnus* Leidy, 1851.** Type ANSP 9235 from Greensand of Burlington Co., N.J. (Leidy, 1865), probably found in the Navesink or Hornerstown Fm. (Parris, 1974). Welles (1962) does not list this genus among his recognized valid genera of plesiosaurs but Parris (1974) has pointed out that recently discovered material is anatomically and stratigraphically equivalent to Leidy's type material and favors retaining the name.

Referred specimens: NJSM 11262 from upper Navesink (= New Egypt) Fm., Daminger Farm, Harrison Township, Gloucester Co., N.J.; ten vertebrae (Parris, 1974). NJSM 6652 and 6653 have no associated data, but adherent matrix is similar to Navesink Fm. NJSM 12201 is an oxidized, worn tooth found reworked into Pensauken Gravel (Pleistocene) from Big Brook, Marlboro Township, Monmouth Co., N.J. NJSM 12197 is a similarly worn and iron-stained vertebral centrum from the Harding Farm, Hop Brook, Holmdel, Monmouth Co., N.J., probably out of the Navesink Fm. by way of Pleistocene gravel. All in situ occurrences are Maastrichtian.

= *Discosaurus vetustus* Leidy, 1851. From Burlington Co., N.J. Parris (1974) synonymizes this taxon with *C. magnus*.

?*Cimoliasaurus* sp. or Cf. *Cimoliasaurus*. Referred specimens: YPM 449. A plesiosaur pubis from Navesink (= New Egypt) Fm., Cream Ridge Marl Co. pit, John Meirs Farm, Cream Ridge, Monmouth Co., N.J. (Baird, 1984).

PU 21514 (isolated vertebral centrum), PU 21630 (tooth), and NJSM 12204 (broken centrum)—From Navesink Fm., Harding Farm, Hop Brook, Holmdel, Monmouth Co., N.J.

NJSM 12198—Two broken centra from Bell Labs, Hop Brook, Holmdel, Monmouth Co., N.J. Reworked into Pleistocene gravels.

NJSM 12505—Cast made from isolated tooth in private collection of Lawrence Decina, from Severn Fm., Landover, Maryland (see Baird, 1986c).

Plesiosauria indet.

NJSM 12202 (fragment of centrum) and NJSM 12203 (fragment of phalanx), both from Navesink Fm.(?), redeposited in Pleistocene gravels, Big Brook, Marlboro, Monmouth Co., N.J.

Plesiosauria *nomina vana*

Nomina vana (Welles, 1952, 1962):

Taphrosaurus lockwoodi Cope, 1869-1870. Raritan Fm. Type lost (Miller, 1955).

Cimolisaurus (*Discosaurus*) *planior* (Leidy, 1870). New Jersey. Type lost (Miller, 1955).

Plesiosaurus brevifemur Cope, 1875. From Hornerstown Fm., Barnsboro, Gloucester Co., N.J. Type lost (Miller, 1955; Parris, 1974).

Elasmosaurus orientalis Cope, 1869-1870. Type AMNH 1409 from Marshalltown Fm., Swedesboro, Gloucester Co., N.J. (Miller, 1955; Baird, 1986c).

Infraclass Archosauromorpha
Superorder Archosauria
Order Crocodylia
Suborder Mesosuchia
Family Dyrosauridae

Hyposaurus

Total stratigraphic range: Upper Cretaceous to Eocene.

***Hyposaurus rogersii* Owen, 1849.** Hornerstown Fm. of many localities; type, collected by Henry Darwin Rodgers, came from the greensand "near Big Timber Creek" probably in the vicinity of Blackwood where many ANSP specimens of *H. rogersii* were collected (Parris, 1986). Specimens at YPM, AMNH, ANSP, and NJSM were also obtained from Hornerstown, Monmouth Co.; Birmingham, Burlington Co.; White Horse, Camden Co.; Inversand Pit, Sewell, and Barnsboro, Gloucester Co., N.J. An anomalous record is ANSP 9648, from Newcastle Co., Delaware, questionably assigned by Miller (1955) to the Navesink; if this is true, then as Parris (1986) points out, this is the only non-Hornerstown Fm. specimen known. Since *H. rogersii* is found in the lower and upper portions of the Hornerstown, its stratigraphic range would appear to span the Maastrichtian-Danian boundary. Parris recognizes only one valid species of *Hyposaurus*, *H. rogersii*, in North America, and sinks the following taxa:

= *H.* (*Goniopholis*) *ferox* Marsh, 1871
= *H.* (*Goniopholis*) *fraterculus* Cope, 1869-1870
= *H.* (*Goniopholis*) *natator* Troxell, 1925

Suborder Eusuchia
Family Alligatoridae

Allognathosuchus

Aff. *Allognathosuchus*. Button teeth of a small alligatorine, lower Marshalltown Fm., Ellisdale, Monmouth Co., N.J. (Parris et al., 1987). If this assignment is correct, this is a stratigraphic range extension from Eocene-Paleocene down into the Campanian. Included in NJSM 14506, 14190, 14221, 14222-14225, 14580.

Diplocynodon

***Diplocynodon* sp.** Isolated scutes, lower Marshalltown Fm., Ellisdale, Monmouth Co., N.J., NJSM 14597, 14363 (Parris et al., 1987). MFL, lower Hornerstown Fm., Inversand Pit, Sewell, Gloucester Co., N.J.; scutes, jaw, teeth, vertebrae, and limb bones, NJSM 11902, 11903 (Gallagher et al., 1986). This also represents a range extension from the Eocene back to the Campanian.

Procaimanoidea

Cf. *Procaimanoidea*. MFL, basal Hornerstown Fm., Inversand Pit, Sewell, Gloucester Co., N.J. NJSM 11305 and 11885, both jaw sections with teeth, and scutes (Gallagher et al., 1986). Another range extension, from the Eocene back into the Maastrichtian.

Bottosaurus

***Bottosaurus harlani* Meyer, 1832.** Type ANSP 9226 from Hornerstown Fm., Birmingham, Burlington Co., N.J. (Miller, 1955). Also NJSM 11265 from MFL, lower Hornerstown Fm., Inversand Pit, Sewell, Gloucester Co., N.J. (Gallagher et al., 1986). Latest Maastrichtian.

Family Crocodylidae

Brachychampsa

Cf. *Brachychampsa*? Lower Marshalltown Fm., Ellisdale, Monmouth Co., N.J.; numerous specimens, mostly isolated entire and broken teeth and scutes, in NJSM (Gallagher et al., 1986; Parris et al., 1987). Campanian.

Deinosuchus

Total stratigraphic range: Upper Cretaceous.

***Deinosuchus rugosus* Emmons.** Lower Marshalltown Fm., Ellisdale, Monmouth Co., N.J. NJSM 10854, 12463, 13772, 13933,

13929 (Gallagher et al., 1986; Parris et al., 1987). Large dermal osteoscute, tooth, large pubis; comparable in size and morphology to similar material from Phoebus Landing, North Carolina, assigned to *D. rugosus* by Baird and Horner (1979). Campanian.

Leidyosuchus

Total stratigraphic range: Upper Cretaceous to Eocene.

***Leidyosuchus* sp.** Lower Marshalltown Fm., Ellisdale, Monmouth Co., N.J. NJSM 13099, 14598 (Gallagher et al., 1986; Parris et al., 1987). Also NJSM 14729, lower Marshalltown Fm., Cambridge Crossing, Mount Laurel, Burlington Co., N.J. Mostly teeth. Campanian.

Thoracosaurus

Total stratigraphic range: Upper Cretaceous.

***Thoracosaurus neocesariensis* (DeKay, 1842).** Type missing (Miller, 1955); specimen was from Vincentown Fm., Big Timber Creek, Gloucester Co., N.J. Numerous specimens of this form are known from Navesink, Hornerstown, and Vincentown Fms. This gives the taxon a chronostratigraphic range from the Maastrichtian to the Dano-Montian. Carpenter (1983) has aptly discussed the taxonomic problems of the genus *Thoracosaurus*, and recognizes but one species, *T. neocesariensis*; he sinks or synonymizes the following taxa:

= *T. basificus* Owen. Vincentown Fm., Vincentown, Burlington Co., N.J.

= *T. meirsanus* Troxell, 1925. Hornerstown Fm., Hornerstown, Monmouth Co., N.J. Type YPM: 404.

= *Holops brevispinus* Cope, 1867. Burlington Co., N.J. Type: AMNH 1445.

= *H. cordatus* Cope, 1869. New Jersey. Type: AMNH 2206.

= *H. glyptodon* Cope, 1869. Hornerstown Fm., Barnsboro, Gloucester Co., N.J.

= *H. pneumaticus* Cope, 1869. Harrisonville, Gloucester Co., N.J. Type: AMNH 2217.

= *Crocodilus basitruncatus* Owen, 1849. Vincentown Fm., Big Timber Creek, Gloucester Co., N.J. Type missing (Miller, 1955).

= *C. obscurus* Leidy, 1856. Hornerstown Fm., Barnsboro, Gloucester Co., N.J. Type: RU 1-K.-V.-12 (now at AMNH). Also ANSP 9185-7 from Hornerstown Fm., Pemberton.

***T. neocesariensis*.** MFL, basal Hornerstown Fm., Inversand Pit, Sewell, N.J. NJSM 11885.

***T. neocesariensis*.** Teeth, scutes, and fragmentary vertebrae in private collections, from Severn Fm., middle Maastrichtian, Landover, Prince Georges Co., Maryland (Baird, 1986c).

***T. neocesariensis*.** ANSP 9374, 9381, Vincentown limestone, Big Timber Creek, Gloucester Co., N.J. ANSP 9364, Vincentown Fm., from limestone, Blackwood. ANSP 9435, 9358, Navesink Fm.(?), Mt. Holly (Miller, 1955). ANSP 10079, Hornerstown Fm.(?), Vincentown (Miller, 1955). ANSP 9437, 9361-3, 9365, 9415, 9420-4, 9357.

***Thoracosaurus* sp.** Basal Hornerstown Fm., Crosswicks Creek, Monmouth Co., N.J. NJSM 12215.

***Thoracosaurus* sp.** Mt. Laurel-Wenonah Fms., Big Brook, Monmouth Co., N.J. (Gallagher et al., 1986), MAPS 1231 (teeth), 1205 (bones).

***Thoracosaurus* sp.** ANSP 9553, Hornerstown Fm., Birmingham, N.J.

***Thoracosaurus* sp.** ANSP 9382, Gloucester Co., N.J.

***Thoracosaurus* sp.** YPM 278, 280, 281, Hornerstown Greensand.

***Thoracosaurus* sp.** YPM 283, Mullica Hill, Hornerstown Fm.(?) (Miller, 1955).

***Thoracosaurus* cf. *neocesariensis*.** Lower jaw; MFL, basal Hornerstown Fm., Blackwood Terrace, Gloucester Co., N.J. ANSP unnumbered (cited as *Thoracosaurus* sp. by Gallagher, 1984).

Cf. *Holops* sp. = *Thoracosaurus*. NJSM 11071, fragments of vertebrae, scutes, limb bones; Hornerstown Fm. (probably upper portion), Evesham Township, Burlington Co., N.J. (SW branch of Rancocas Creek where it crosses Rt. 70); Paleocene.

Order Pterosauria
Suborder Pterodactyloidea
Family Ornithocheiridae

Cf. *?Titanopteryx*. Cervical vertebra, basal Navesink Fm., early Maastrichtian, Atlantic Highlands, Monmouth Co., N.J. (Baird, 1983).

Ornithocheiridae indet.

Cervical vertebra (PU 21820) and humerus (PU 22359) from "Blue Area" spoil piles, north bank of Chesapeake and Delaware Canal, Summit Bridge, Delaware; probably Campanian. Femur and tibia (PU 21821) from canal bank on south side, Summit Bridge, Delaware; Merchantville Fm., Early Campanian (Baird and Galton, 1981).

Superorder Dinosauria

The history of East Coast dinosaur taxonomy is another fine example of the tangle of confused nomenclature created from naming fragmentary remains. In this section I will use a parsimonious approach in an attempt to avoid the pitfalls of oversplitting; I have retained the old names for some specimens merely as a way of showing the taxonomic "noise-to-signal" ratio inherent in counting all the dubious names. For instance, it would now appear that the various theropod remains both large and small should all be synonymized under *Dryptosaurus*, the smaller forms being regarded as juveniles (Denton and Gallagher, 1989). Similary, many of the old hadrosaur names are highly suspect, but have been mentioned in order to construct as complete a synonymy as possible.

Order Saurischia
Suborder Theropoda
Family Dryptosauridae

Dryptosaurus Marsh

= *Laelaps* Cope, 1866

***Dryptosaurus aquilunguis* (Cope).** Type: ANSP 9995, also catalogued under ANSP 10006 (+ AMNH 2438). Navesink (= New Egypt) Fm. (= Chocolate Marl), Maastrichtian. Teeth are ANSP 9995; claw, phalanx, vertebrae, tibia, fibula, portion of articular, portion of metatarsal, portions of two humeri, left femur, phalanges, two pubes and a portion of the maxilla are ANSP 10006.

AMNH 2438. "Kleptotype" of *D. aquilunguis*, Cope Collection, AMNH purchase of 1902; left metatarsal IV, evidently from type ANSP 9995/10006. AMNH 2438 also contains a smaller long shaft bone with ends broken off. Locality given: "West Jersey Marl Pit, Barnsboro, Mantua Twp., Gloucester Co., N.J. Collr: E. D. Cope, 1870-75." This bone may also be part of the holotype.

AMNH 7624. Incomplete tooth (tip broken). Label gives locality as "About 6 mi. NW of Freehold, N.J." Horner (1979) lists this as Maastrichtian (Mount Laurel, Navesink, or New Egypt Fms.), but on the New Jersey Geological Map (Lewis and Kümmel, 1910-1912) this is mapped as Englishtown-Marshalltown Fm. area, hence it should be regarded as Campanian.

MAPS A1226a. Listed as *Ornithomimus antiquus* (Leidy) (caudal vertebrae); identified by Horner (1979) as *D. aquilunguis* (Cope).

NJSM 14256. Cf. *Dryptosaurus*; tooth, Mt. Laurel Fm., Hop Brook, Holmdel, Monmouth Co., N.J.

NJSM specimens. Cf. *Dryptosaurus*: NJSM 13087 (long bone shaft); 12436, 13095, 13734, 14158, 14404 (all teeth); 14682 (proximal phalanx-manus from Logjam Site). All from basal Marshalltown Fm., Campanian, Ellisdale, Monmouth Co., N.J. (Gallagher et al., 1986; Parris et al., 1987; Denton and Gallagher, 1989).

The following forms are regarded here as dryptosaurs:
Coelosaurus antiquus Leidy (= *Dryptosaurus antiquus*)
Ornithomimus (*Coelosaurus*) *antiquus* (Leidy). Type ANSP 9222, tibia from Navesink (= New Egypt) Fm., Maastrichtian, Burlington Co., N.J.
Dryptosaurus macropus = *D. macrops* (Miller, 1955). Type lost.

ANSP 9151. *O.* (*C.*) *antiquus* (Leidy), listed with 9150 in Horner (1979), which is a large crocodilian vertebra, cf. *Deinosuchus rugosus*. ANSP 9151 is a caudal vertebra from Burlington Co., N.J., formation indeterminate but possibly Navesink.

NJSM 12503. *O. antiquus*, cast made from pedal phalanx in private collection of E. Hartstein; Chesapeake and Delaware Canal, spoil piles near St. Georges, New Castle Co., Delaware, Marshalltown Fm.(?), Campanian.

AMNH 2549, 2550, 2551, 2552, 2553 listed by Horner (1979); MAPS A12106; PU 21825, 22361, all given Maastrichtian age, Mt. Laurel, Navesink, or New Egypt Fm. All listed as *C. antiquus*.

PU 21795. Merchantville Fm., Campanian, Chesapeake and Delaware Canal (Baird and Galton, 1981). (Merchantville, Woodbury, Marshalltown Fm.; Horner, 1979.) MAPS 12106 listed as *Dryptosaurus*? sp. (phalanx) from Wenonah Fm.

Dryptosauridae indet.

NJSM 16664, cast made from tooth in private collection of E. Lauginiger, from basal Marshalltown Fm., Cambridge Crossing Executive Park, Mt. Laurel, Burlington Co., N.J.; probably Campanian.

Theropoda indet.

NJSM 14434, 14504, 14236, 13096. Basal Marshalltown Fm., Ellisdale, Monmouth Co., N.J. (Gallagher et al., 1986; Parris et al., 1987).

PU 166760. Carnosauria indet., partial metatarsal from Raritan or Magothy Fm., Cenomanian to Santonian, from Roebling, Burlington Co., N.J. (Baird, 1989).

Footprint. Rutgers Museum of Geology. Raritan Fm., Cenomanian (Baird, 1989).

Diplotomodon horrificus Leidy, 1865 (= *Tomodon horrificus* Leidy). Type: ANSP 9680, large partial tooth from Mullica Hill, Gloucester Co., N.J., either from Navesink or Hornerstown Fm., Maastrichtian. Placed by Miller (1955) in Mosasauridae. Genus and species based on single tooth; *nomen dubium*.

Order Ornithischia
Suborder Ornithopoda
Family Hadrosauridae
Subfamily Hadrosaurinae

Hadrosaurus Leidy, 1858.

Total stratigraphic range: Campanian to Maastrichtian.

***Hadrosaurus foulkii* Leidy, 1858.** Type: ANSP 10005 from Woodbury Fm., Haddonfield, Camden Co., N.J. Baird and Horner (1977) synonymize:
= *Ornithotarsus immanis* Cope 1869—Type YPM 3221 from Woodbury Fm., Campanian, shore of Raritan Bay, 2 1/2 miles east of Keyport, Monmouth Co., N.J. Distal end of tibia and fibula with astrgalus and calcaneum.
= *O. immanis*, ANSP 8956—From Merchantville Fm. (but actually Woodbury Fm.; see Section 2), Campanian, Merchantville, Camden Co., N.J. Left metatarsal III (see Woolman, 1896).
= *H. cavatus* Cope 1871—Type: AMNH 1390, from "Greensand No. 5, New Jersey." Consists of four middle caudals.

In addition, Parris et al. (1988) reassigned *Hypsibema crassicauda* to the Hadrosaurinae; reported from lower Marshalltown Fm., Ellisdale, Monmouth Co., N.J., NJSM 12702 (Gallagher et al., 1986).

***H. foulkii* Leidy.** AMNH 7626 from "6 miles NW of Freehold, N.J." This would place it in the Englishtown-Marshalltown outcrop area, hence Campanian. Partial jaw (lower left?).

***H. foulkii* Leidy.** PU 21813 and 21824 (now at YPM) from "5 miles NW of Freehold on Rte. 9 at Manalapan-Marlboro township line, 3/4 mi. N of Gordon's Corner, Monmouth Co., N.J." This is Matawan Group outcrop area, hence Campanian. Partial jaw.

***"Hadrosaurus" minor* (Marsh, 1879).** Type: YPM 1660, from Barnsboro, Gloucester co., N.J. Miller (1955) lists provenance as Hornerstown Fm.(?); more likely Chocolate marl, or Navesink Fm., hence Maastrichtian.

***H. minor*.** Hornerstown Fm., Maastrichtian, Sewell, Gloucester Co., N.J., ANSP 15237 (Miller, 1955).

***H. minor*.** ANSP 15202, Maastrichtian (Horner, 1979).

***H. minor*.** ANSP 15202, Navesink Fm. (top), Maastrichtian, Inversand Pit, Sewell, Mantua Twp., Gloucester Co., N.J. Fragments of ribs, right pubis, portion of right ischium, right and left femur, portion of left fibula, vertebrae, chevrons, and numerous unidentified fragments (Colbert, 1948).

***H. minor*.** ANSP 10007, right femur lacking proximal end, West Jersey Marl Co. pits, Barnsboro, Gloucester Co., N.J., Maastrichtian. Cope's first dinosaur (Osborn, 1931).

***H. minor*.** NJSM 11880, left tibia, Navesink Fm., Maastrichtian, Inversand Pit, Sewell, Gloucester Co., N.J.

***H. minor*.** NJSM 15136, vertebral centrum, uppermost Navesink Fm., just below contact with overlying Hornerstown Fm., Maastrichtian, Inversand Pit, Sewell, Gloucester Co., N.J.

Cf. *"Edmontosaurus"*. NJSM 12132, quadrate, basal Hornerstown Fm., Campanian, Ellisdale, Monmouth Co., N.J. (Gallagher et al., 1986).

Subfamily Lambeosaurinae

Lambeosaurinae indet. (*fide* D. Baird).

Lambeosaur? YPM 3216 from Navesink (= New Egypt) Fm., Maastrichtian, West Jersey Marl Co. Pit, Barnsboro, Gloucester Co., N.J. Radius and ulna.

Lambeosaur? ANSP 15550, Monmouth Co., N.J., probably Maastrichtian. (Figured in Leidy, 1865, pl. 17.) Humerus, coll. of Dr. John H. Slack.

Lambeosaur? NJSM 11961, top of Navesink (New Egypt) Fm., Maastrichtian, Inversand Pit, Sewell, Mantua Twp., Gloucester Co., N.J. Radius and ulna.

Hadrosauridae indet.

Ellisdale, Monmouth Co., N.J., basal Marshalltown Fm.: NJSM 11365, 14036, 14163, 14510, 12703, 13771, 13089, 14229, 14582, 14514, 13086, 12133, 13932, 12134, 14266, 14201, 13897, 13104, 14590, 14227, 14228, 14387, 13090, 12713, 15058. Mostly teeth, but also cranial and post-cranial fragments. Campanian.

ANSP 8701, 8702, 8703, 8704 (same individual), probably a juvenile. From Monmouth Group, probably Maastrichtian, near Ayrestown (now Lumberton), Burlington Co., N.J. Distal end of tibia plus two metatarsals. ANSP 8075, another metatarsal, is missing.

ANSP 10001, 10002. ". . . from the Marl of New Jersey—Swedesboro." A very large hadrosaur femur; ANSP 10000 is also part of this bone, but I was unable to locate it in the collection. Probably Matawan Group, hence Campanian.

ANSP 14619. Found loose at bottom of a well, Matawan, Monmouth Co., N.J. Matawan Group, Campanian. Right femur, proximal end.

ANSP 15715. Shaft of right femur, "from the Greensand of New Jersey." Maastrichtian?

ANSP 15716. Proximal portion of left humerus. No locality data.

ANSP 15717. Hadrosaur metatarsal with borings on one side. Benjamin Franklin's dinosaur? (*fide* D. Baird); if so, from Woodbury, Gloucester Co., N.J.; probably Campanian.

MAPS 1213a. Mount Laurel Fm., Campanian, Big Brook, Marlboro, Monmouth Co., N.J. Jaw fragment and teeth.

MAPS 1213b. Basal Navesink Fm., Maastrichtian, Atlantic Highlands, Monmouth Co., N.J.

MAPS 1214. Cf. *Hadrosaurus* sp. Fragment of distal end of tibia, comparable in morphology and size to "*Ornithotarsus immanis*." Mount Laurel Fm., Campanian, Holmdel, Monmouth Co., N.J.

MAPS A1215a. Mount Laurel Fm., Chesapeake and Delaware Canal, Delaware (Baird and Galton, 1981). Vertebra.

MAPS A1215b. Campanian(?), Manalapan, Monmouth Co., N.J.

MAPS A1215c. Woodbury Fm., Campanian, Matawan, Monmouth Co., N.J. Vertebra.

PU 19731. Marshalltown Fm., Campanian, Chesapeake and Delaware Canal, Delaware (Baird and Galton, 1981). Limb fragments.

PU 21824. Manalapan, Monmouth Co., N.J., probably Matawan Group, Campanian. Partial left jaw (a cast).

PU 22430. Merchantville Fm., Campanian, Swedesboro, Gloucester Co., N.J. Left manus phalanx II-2.

PU 22417. Merchantville Fm., Campanian, Chesapeake and Delaware Canal, Delaware. Partial caudal vertebra.

PU 22177. Navesink or Mount Laurel-Wenonah Fm., Big Brook, Monmouth Co., N.J. Dentary tooth.

NJSM 6646. Matawan Group, Campanian, Pennsylvania Clay Company pit, Matawan, Monmouth Co., N.J. Portion of femur.

NJSM 13704. Merchantville Fm.(?), Campanian, near Matawan, Monmouth Co., N.J. Jaw fragment.

NJSM 14639. Cf. *Hadrosaurus*. Navesink Fm.(?), Milford Brook, Manalapan Twp., Monmouth Co., N.J. Prefrontal.

NJSM 14662. Cf. *Hadrosaurus*, isolated tooth, collected by Donald Clements. Englishtown Fm., Campanian, Cambridge Crossing Executive Park, Mt. Laurel, Burlington Co., N.J.

AMNH 2344. *Hadrosaurus* sp. New Jersey, Cretaceous; mostly fragments, 28 pieces, adhering greensand matrix.

AMNH 1460. Three caudal vertebrae; probably of mixed provenance. Adherent dark clay with shell fragments on one specimen; this is probably Woodbury Fm., Cretaceous, New Jersey.

AMNH 3247. Proximal end of radius. Schenk Farm, near Marlboro, N.J. Navesink Fm.(?), Maastrichtian(?). Rib.

AMNH 3249. Large worn caudal centrum. Schenk Farm, near Marlboro, N.J. Navesink Fm.(?), Maastrichtian(?).

AMNH 3250. Portion of shaft of leg bone. Schenk Farm, near Marlboro, N.J. Navesink Fm.(?), Maastrichtian(?).

AMNH 2343. Hadrosaurinae indet. Monmouth Co., N.J.

YPM 745. "*Hadrosaurus minor*." Navesink Fm., Maastrichtian, West Jersey Marl Co. pit, Barnsboro, Gloucester Co., N.J. Partial left and right tibia, distal end of femur, rib.

YPM 1587. "*H. minor*." Matawan Group, Campanian, Swedesboro, Gloucester Co., N.J. Fragment of femur.

YPM 1593. "*H. minor*". Navesink (= New Egypt) Fm., Maastrichtian, Mullica Hill, Gloucester Co., N.J. Posterior dorsal vertebral centrum.

YPM 7896. "*H. minor*". Presumably Navesink Fm., Maastrichtian, West Jersey Marl Co. pit, Barnsboro, Gloucester Co., N.J. Left femur, tibia, and distal end of fibula, astragalus, plus fragments.

YPM 7898. Hadrosaur? Navesink (= New Egypt) Fm., Maastrichtian, West Jersey Marl Co. pit, Barnsboro, Gloucester Co., N.J. Left coracoid.

Suborder Ankylosauria
Family Nodosauridae

Nodosauridae indet.

PU 21560. Dermal osteoscute cast; original lost. Pebbly layer at base of Navesink Fm.(?) ca. 1 mi. upstream from Boundary Road Bridge, Marlboro Twp., Monmouth Co., N.J. This is probably Wenonah or Marshalltown Fm., making it Late Campanian. (Horner, 1979.)

PU 21775. Caudal centrum. From Navesink Fm., Maastrichtian, at Poricy Brook, Middletown Twp., Monmouth Co., N.J.

Birds

Bird fossils are among the rarest of remains in the New Jersey Upper Cretaceous-Lower Tertiary section, and it has been only in recent years that their true stratigraphic position has been understood (Baird, 1967; Olson and Parris, 1987). Moreover, the fragile nature of bird bones indicates some important information about the taphonomy of their occurrence.

Class Aves
Subclass Neornithes
Superorder Neognathae
Order Diatrymiformes
Family Diatrymatidae

Diatryma

***Diatryma regens* (Marsh, 1894)** = *Barornis regens* (Marsh, 1894). YPM 417. Manasquan Fm., Early Eocene, Ypresian, Manasquan River, Squankum, Monmouth Co., N.J. Doral phalanx.

Order Charadriiformes
Family Graculavidae

Graculavis Marsh 1872

***Graculavis velox* Marsh 1872.** Type: YPM 855, from Hornerstown, Upper Freehold Twp., Monmouth Co., N.J., "either basal Hornerstown Fm. or Navesink Fm." (Olson and Parris, 1987).

***G. velox*?** NJSM 11854. MFL, basal Hornerstown Fm., Inversand Co. pit, Sewell, Mantua Twp., Gloucester Co., N.J. (Olson and Parris, 1987).

Telmatornis Marsh 1870

= *Graculavis affinis* Marsh, 1870 (Olson and Parris, 1987).

= ?*Paleotringa vetus* Marsh, 1870, type ANSP 13361. Hornerstown Fm., Arneytown, Burlington Co., N.J. (Olson and Parris, 1987).

***Telmatornis priscus* Marsh, 1870.** Holotype YPM 840, distal end of left humerus. From Navesink Fm., pits of Cream Ridge Marl Co., near Hornerstown, Monmouth Co., N.J. (Baird, 1967; Olson and Parris, 1987).

T. affinis. Holotype YPM 845, distal end of right humerus. From Navesink Fm., Maastrichtian, pits of Cream Ridge Marl Co., near Hornerstown, Monmouth Co., N.J. (Baird, 1967; Olson and Parris, 1987).

G. pumilis. Holotype YPM 850, proximal end of right humerus with distal end of right carpometacarpus and associated fragments of long bone shafts. From near Hornerstown, N.J., probably from basal Hornerstown Fm. (Olson and Parris, 1987), hence Maastrichtian.

P. vetus. ANSP 15360, left humerus lacking proximal end. Basal Hornerstown Fm., Maastrichtian, Inversand Pit, Sewell, Mantua Twp, Gloucester Co., N.J. (Olson and Parris, 1987).

T. priscus. NJSM 11853, distal end of left tarsometatarsus. MFL, basal Hornerstown Fm., Inversand Pit, Sewell, Mantua Twp., Gloucester Co., N.J. (Olson and Parris, 1987).

T. priscus. NJSM 11900, proximal end of right ulna. Spoil piles, near Hornerstown, Monmouth Co., N.J.; probably from Hornerstown Fm. (Olson and Parris, 1987).

Anatalavis Olson and Parris, 1987

***Anatalavis rex* (Schufeldt, 1915)** = *Telmatornis rex*. Holotype YPM 902, right humerus lacking proximal end. Referred specimen: YPM 948, left humerus lacking proximal end. Both specimens from

Hornerstown, Upper Freehold Twp., Monmouth Co., N.J. Probably Maastrichtian, basal Hornerstown Fm. (Olson and Parris, 1987).

Laornis Marsh

***Laornis edvardsianus* Marsh, 1870.** Holotype and single specimen YPM 820, distal end of tibiotarsus. From pits of Pemberton Marl Co., Birmingham, Burlington Co., N.J. Probably Maastrichtian, basal Hornerstown Fm. (Baird, 1967; Olson and Parris, 1987).

Palaeotringa Marsh, 1870

***Palaeotringa littoralis* Marsh, 1870.** Holotype YPM 830, distal portion of left tibiotarsus lacking most of inner condyle. From Navesink or Hornerstown Fm., Maastrichtian, Waln's marl pits near Hornerstown, Upper Freehold Twp., Monmouth Co., N.J. (Olson and Parris, 1987).

P. littoralis? NJSM 11303, distal portion of a left humerus. MFL, basal Hornerstown Fm., Maastrichtian, Inversand Co. Pit, Sewell, Mantua Twp., Gloucester Co., N.J. (Olson and Parris, 1987).

***Palaeotringa vagans* Marsh, 1872.** Holotype YPM 835, fragmented distal left tibiotarsal. Navesink or Hornerstown Fm., Maastrichtian, Hornerstown, Monmouth Co., N.J. (Olson and Parris, 1987).

GRACULAVIDAE indet.

NJSM 11302, "abraded distal end of left humerus and associated proximal portion of humeral shaft, proximal end of radius and fragment of shaft of ulna" (articulated wing). MFL, basal Hornerstown Fm., Maastrichtian, Inversand Co. Pit, Sewell, Mantua Twp., Gloucester Co., N.J. (Olson and Parris, 1987).

Order PROCELLARIIFORMES?
Family TYTTHOSTONYCHIDAE

Titthostonyx Olson and Parris, 1987

***Titthostonyx glauconiticus* Olson and Parris, 1987.** Holotype NJSM 11341, "right humerus lacking pectoral crest and other parts of proximal end, where partially reconstructed." MFL, basal Hornerstown Fm., Inversand Pit, Sewell, N.J. (Olson and Parris, 1987).

AVES indet.

ANSP 15713. Distal portion of left ulna. Hornerstown Fm., Maastrichtian (but not *in situ*), Inversand Pit, Sewell, N.J. (Olson and Parris, 1987).

NJSM 12119. Distal end of left femur. Inversand Pit, Sewell, N.J.; spoil piles, probably Hornerstown Fm. but precise stratum unknown.

NJSM 12248. Long bone shaft. MFL, basal Hornerstown Fm., Inversand Pit, Sewell, N.J.

NJSM 14152. Bird bone(?), end of long bone (fragment). Big Brook, Marlboro, Monmouth Co., N.J. Upper Cretaceous?

NJSM unnumbered. Bird bone, broken. Basal Hornerstown Fm., Maastrichtian, Crosswicks Creek, Upper Freehold Twp., Monmouth Co., N.J.

MAMMALS

The discovery of Cretaceous mammals in New Jersey is one of the most recent developments in local paleontology. This material is currently under study and has provided the first specifically identifiable mammal fossils from the Cretaceous of eastern North America (see Grandstaff et al., 1992).

Class MAMMALIA
Subclass ALLOTHERIA
Order MULTITUBERCULATA

***Cimolomys clarki* (Grandstaff et al., 1992).** NJSM 15039 and unnumbered, upper incisor, metapodial, ?lower incisor. Basal Marshalltown Fm., Campanian, Ellisdale, Monmouth Co., N.J.

MULTITUBERCULATA *incertae sedis*

Multituberculata *incertae sedis* (or indet.?). PU 21451, proximal fragment of left femur. Mount Laurel Fm., Early Maastrichtian, Hop Brook, Holmdel Twp., Monmouth Co., N.J. (Krause and Baird, 1979).

Infraclass METATHERIA
Order MARSUPIALIA
Suborder DIDELPHOIDEA
Family DIDELPHIDAE

Alphadon lulli. Basal Marshalltown Fm., Ellisdale, Monmouth Co., N.J. (Grandstaff et al., 1992).

Subclass THERIA
Order TILLODONTIA
TILLODONTIA *incertae sedis*

***Anchippodus riparius* Leidy, 1869.** Holotype ANSP 10338 (missing; Gillette and Colbert, 1976), tooth from Shark River, Monmouth Co., N.J. Eocene or Miocene(?).

THERIA indet.

?Theria indet. NJSM 15040, canine tooth, and NJSM unnumbered, portion of scapula. Ellisdale, Monmouth Co., N.J., Campanian (Parris and Grandstaff, 1989).

(Tables 9-26 follow)

Tables 9 - 26. Stratigraphic Distribution of Cretaceous/Tertiary Fossil Vertebrates in the Northern Atlantic Coastal Plain.

Abbreviations of Formation Names:

Mer	Merchantville Fm.
Wo	Woodbury Fm.
E	Englishtown Fm.
Mar	Marshalltown Fm.
We	Wenonah Fm.
Mt	Mount Laurel Fm.
N	Navesink Fm.
R	Redbank Fm.
T	Tinton Fm.
MFL	Main Fossiliferous Layer
H	Hornerstown Fm.
V	Vincentown Fm.
Man	Manesquan Fm.
SR	Shark River Fm.

Footnotes to tables provide information on guilds and environmental niches occupied by those taxa.

Table 9. Chondrichthyes 1.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Family Hybodontidae														
Hybodus sp.[1]				X		X								
Family Polyacrodontidae														
Lissodon babulski[1]				X		X								
Order Hexanchiformes														
Family Hexanchidae														
Hexanchus agassizi												X	X	X
Hexanchus sp.[2]										X				
Family Heptrachnidae														
Heptranchias howelli[2]														X
Order Squatiniformes														
Family Squatinidae														
Squatina hassei[3]				X		X								

[1]Shallow-water predators, probably duraphagous.
[2]Open-water piscivorous predator.
[3]Angel shark, shallow-water bottom-feeding duraphagous and piscivorous predator.

Table 10. Chondrichthyes 1 (cont'd).

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Order Orectolobiformes														
Family Ginglymostomatidae														
Ginglymostoma globidens[1]				X		X								
G. obliquum[1]													X	X
Order Lamniformes														
Family Odontaspidae														
Odontaspis aculeatus[2]						X								
O. samhammeri[2]				X		X								
O. hardingi[2]						X								

(cont'd)

Table 10 (cont'd)

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Family Odontaspidae (cont'd)														
Striatolamna striata[2]												X		
Synodontaspis holmdelensis[2]				X		X								

[1]Nurse shark, shallow-water bottom-feeding duraphagous and piscivorous predator.
[2]Sand tiger sharks, shallow-water near-bottom duraphagous and piscivorous predator.

Table 11. Chondrichthyes 2.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Family Cretoxyrhinidae														
Cretodus (*Plicatolamna*) *borodini*[1]				X		X								
C. (*P.*) *arcuata*[1]				X	X	X								
Cretolamna (*Lamna*) *appendiculata*[1]				X	X	X						X		
Cretoxyrhina mantelli[1]	X													
Family Otodontidae														
Otodus obliquus[1]												X	X	X
Family Alopiidae														
Paranomotodon (*Oxyrhina*) cf. *angustidens*[2]				X	X	X								
Family Anacoracidae														
Squalicorax (*Corax*) *kaupi*[3]	X	X		X	X	X								
S. (*C.*) *pristodontus*[3]				X	X	X	X			X				
Pseudocorax granti[3]				X										
Family Lamnidae														
Xiphodolamia ensis[4]													X	
Family Mitsukurinidae														
Scapanorhynchus texans[5]	X	X		X		X	X							

[1]Open-water pursuit predators (on fish).
[2]Thresher sharks, open-water pursuit predator (on fish).
[3]Open-water pursuit predator; crow shark.
[4]Open-water piscivorous pursuit predator.
[5]Deep-water predator; goblin shark.

Table 12. Chondrichthyes 3.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Superorder Batomorphii														
Order Rajiformes														
Family Rhinobatidae														
Rhinobatos casieri[1]				X		X								
Pseudohypolophus sp.[1]				X	X	X								
Family Sclerorhynchoidei														
Ankistrorhynchus major						X								
Ischyrhiza mira	X			X	X	X	X			X				
?Sclerorhynchus sp.				X										
Incertae sedis														
Ptychotrygon vermiculata				X		X								
P. hooveri				X										
Family Pristidae														
Pristis amblodon[2]													X	

[1]Guitarfishes, shallow-water duraphagous predators.
[2]Sawfish, piscivorous predator of shallow coastal waters, estuaries and lower parts of large rivers.

Table 13. Chondrichthyes 4.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Order Myliobatoidea														
Family Myliobatidae														
Brachyrhizodus wichitaensis[1]			X		X									
Myliobatis jugosus[1]												X		
Family Rhombodontidae														
Rhombodus laevis				X	X	X								
Order Chimaeriformes														
Family Chimaeridae														
Edaphodon stenobyrus[2]										X				
E. mirificus[2]							X			X				
Ischyodus bifurcatus[2]	X	X				X	X							
Ischyodus cf. *thurmanni*[2]										X				

[1]Eagle rays, shallow water duraphagous predators.
[2]Ratfish, deep-water predators, duraphagous, but also take small fish.

Table 14. Osteichthyes 1.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Order Acipensiformes														
Suborder Acipenseroidei														
Acipenser sp.[1]				X						X				
Order Lepisosteiformes														
Atractosteus sp.[2]				X										
Leisosteus sp.[3]				X	X	X								
Order Pycnodontiformes														
Family Pycnodontidae														
Anomaeodus (*Pycnodus*) *phaseolus*[4]	X			X	X	X	X							
Division Teleostei														
Order Ichthyodectiformes														
Family Ichthyodectidae														
Xiphactinus audax[5]				X	X	X	X							
Order Elopiformes														
Family Albulidae														
Albula sp.[6]				X										
Family ?Phyllodontidae														
Paralbula casei				X	X	X								

[1]Sturgeon, anadromous bottom-feeding duraphagous/insectivorous/piscivorous predator.
[2]Gars, estuarine to freshwater piscivorous predator.
[3]Freshwater piscivorous predator.
[4]Shallow-water duraphagous predator.
[5]Open-water predator.
[6]Bonefish, shallow-water duraphagous predator; also takes small fish.

Table 15. Osteichthyes 2.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Order Aulopiformes														
Family Enchodontidae														
Enchodus ferox[1]	X	X		X	X	X	X			X				
Order Tetradontiformes														
Family Trigonodontidae														
Stephanodus sp.[2]				X	X	X								

[1]Open-water predator.
[2]Duraphagous predator.

Table 16. Amphibia.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Order Urodela														
Family Batrachosauriididae														
Cf. *Opistotriton* sp.[1]				X										
Order Anura														
Family Paleobatidae														
Paleobatidae indet.[2]				X										

[1]Freshwater predator.
[2]Freshwater/terrestrial insectivore.

Table 17. Reptilia: Chelonia 1.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Subclass Testudinata														
Suborder Pleurodira														
Family Pelomedusidae														
Bothremys cooki[1]	X									X				
B. barberi[1]				X										
Taphrospys sulcatus[1]										X				
Suborder Cryptodira														
Family Dermatemydidae														
Adocus beatus				X						X				
Agomphus turgidus										X				
Family Trionychidae														
Trionyx halophila[2]	X			X										
Trionyx sp.[2]					X	X								
Superfamily Chelonoidea														
Family Protostegidae														
Cf. *Protostega* sp.[3]						X								
Pneumatoarthrus peloreus[3]							X							
Atlantochelys mortoni[3]							X							
Neptunochelys tuberosa[3]							X							

[1]Duraphagous predators.
[2]Omnivorous ambush/pursuit predator of slow-moving freshwater and estuainre habitats, occasionally washed out to sea.
[3]Open-water omnivores, duraphagous/herbivorous (by analogy with modern leatherback).

Table 18. Reptilia: Chelonia 2.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Family Toxochelyidae														
Dollochelys atlantica[1]		X								X	X			
Osteopygis emarginatus[1]							X			X		X		
Peretresius ornatus[1]							X			X				
Prionochelys cf. *nauta*[1]										X				
Family Cheloniidae														
Corsochelys sp.[1]				X			X							

[1]Open-water omnivores; herbivorous/duraphagous (by analogy with modern cheloniids).

Table 19. Reptilia: Lepidosauria 1.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Order Squamata														
Family Scineidae														
?*Contogenys*[1]				X										
Family Anguidae														
?Anguidae indet.				X										
Family Mosasauridae														
Clidastes iguanavus[2]	X			X										
Globidens alabamaensis[2]				X										
Halisaurus platyspondylus[2]	X					X	X							
Liodon sectorius[2]							X			X				
Mosasaurus conodon[2]							X			X				
M. dekayii[2]							X			X				
M. maximus[2]							X			X				
Plioplatecarpus depressus[2]							X			X				
Prognathodon rapax[2]							X			X				

[1]Small terrestrial predators.
[2]Open-water ambush predators, duraphagous?

Table 20. Reptilia: Lepidosauria 2.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Suborder Serpentes														
Family Boidae														
Cheilophis huerfanoensis[1]												X		
Family? Paleophidae														
Paleophis lattoralis[1]												X	X	
P. halidanus[1]													X	
P. grandis[1]														X
Pterosphenus cf. *schucherti*[1]												X		

[1]Marine snakes, nearshore predators.

Table 21. Reptilia: Plesiosauria.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Family Plesiosauridae														
Cimoliasaurus magnus[1]							X							
Plesiosauria indet.				X						X				

[1]Open-water ambush predators.

Table 22. Reptilia: Crocodylia.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Family Dryosauridae														
Hyposaurus rogersii[1]										X				
Family Alligatoridae														
Cf. *Allognathosuchus* sp.[2]				X										
Diplocynodon sp.[2]				X						X				
Cf. *Procaimanoidea* sp.[2]										X				
Bottosaurus harlani[2]										X				
Family Crocodylidae														
Cf. *Brachychampsus* sp.[3]										X				
Deinosuchus rugosus[3]				X										
Cf. *Leidyosuchus* sp.[3]				X										
Thoracosaurus neocesariensis[3]						X	X			X		X		

[1]Open-water ambush predator.
[2]Estuarine, freshwater, and nearshore ambush predators; some forms possibly duraphagous.
[3]Estuarine/open-water ambush predators.

Table 23. Reptilia: Pterosauria.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Family Ornithocheiridae														
Cf. ?*Titanopteryx* sp.[1]							X							
Ornithocheiridae indet.	X													

[1]Volant predator/scavanger.

Table 24. Reptilia: Dinosauria.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Order Saurischia														
Dryptosaurus aquilunguis[1]				X		X	X							
Order Ornithischia														
Hadrosaurus foulkii[2]	X	X		X										
"*Hadrosaurus*" *minor*[2]							X							
?Lambeosaurinae indet.[2]							X							
Hadrosauridae indet.[2]	X	X		X		X	X							
Nodosauridae indet.[2]					X		X							

[1]Large terrestrial predator.
[2]Large terrestrial herbivore.

Table 25. Aves.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Order Diatrymatidae														
Diatryma regens[1]													X	
Order Charadriiformes														
Family Graculavidae[2]														
Graculavis velox										X				
Telmatornis priscus										X				
T. affinis							X			X				
Antalavis rex							X							

(cont'd)

Table 25 (cont'd)

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Family Graculavidae (cont'd)														
Laornis edvardsianus										X				
Palaeotringa littoralis										X				
P. vagans										X				
Family Titthostonychidae														
Titthostonyx glauconiticus										X				

[1]Terrestrial carnivore.
[2]"Shorebirds"—waders, swimmers, and divers of marshes, lakes, beaches, and coastal waters; primarily predators.

Table 26. Mammals.

	Mer	Wo	E	Mar	We	Mt	N	R	T	MFL	H	V	Man	SR
Order Multituberculata														
Cf. *Cimolomys clarki*[1]				X										
Multituberculata indet.				X		X								
Order Marsupialia														
Alphadon lulli[2]				X										
Order Tillodontia														
Anchippodus riparius[3]														X
Subclass Theria														
Theria indet.				X										

[1]Terrestiral insectivore.
[2]Terrestrial omnivore.
[3]Terrestrial herbivore.

6. Conclusions and Summary

Stratigraphic Discussion

Some workers have favored an angular unconformity at the K/T boundary in New Jersey (Minard et al., 1969; Owens and Sohl, 1969). Such an unconformity has not been observed but inferred; rather, this hypothesis is based on the thicker stratigraphic sequence of Monmouth Group Maastrichtian deposits in the northeastern area of the K/T outcrop belt in New Jersey. In this view, the angular unconformity cuts out succeedingly older formations along strike to the southwest, thinning the sequence until the Hornerstown overlies the Navesink in southern New Jersey and the Navesink itself is completely missing from outcrop at the Chesapeake and Delaware Canal (Owens et al., 1970).

There are several problems with this model. First, as noted above the outcrop trend of the Navesink does not intersect the channel of the C & D Canal, but strikes south of it (see Lewis and Kümmel, 1910-1912). Secondly, the removal of 33 m of Red Bank and Tinton Formations occurs between Atlantic Highlands and the Crosswicks Creek area near New Egypt, by thickness measurements derived from several sources (see Table 28).

Extrapolating this further along strike, this means that 35 miles to the southwest another 30-35 m of sedimentary rock should have been eroded, removing the entire Maastrichtian section; this is demonstrably not the case, since the Navesink and Mount Laurel are still present at this distance along strike in Gloucester County, and indeed, the thickness of the Navesink as seen in some sections is closely comparable between Monmouth and Gloucester Counties (see, for example, Sections 6 and 7 in Appendix). Thirdly, we can use the data and diagram presented by Owens and Sohl (1969, p. 238) to analyze this proposal; according to their cross-section, if we project the angle of the unconformity they depict, then the Navesink should be entirely missing southwestward along strike by Mount Holly in Burlington County, the Mount Laurel, Wenonah and Marshalltown should pinch out in Gloucester County and by the Chesapeake and Delaware Canal in eastern Delaware the entire Campanian section should be totally cut out and the youngest exposures available would be in the Santonian Magothy Formation. This pattern is also demonstrably not the case; the Mount Laurel actually thickens to the southwest. Finally, virtually all the stratigraphic units thin to the southwest, with the exception of, as said, the Mount Laurel, which appears to thicken at the expense of the Wenonah. This means that the Paleocene Rancocas Group and the Campanian Matawan Group also thin along strike.

A much better way of explaining this pattern is to view it in terms of varying depositional environments changing through time and space in response to shifting centers of maximum deposition and eustatic sea-level fluctuations (Gallagher, 1984). In this model, facies changes are primarily involved in the variable nature of the K/T sequence sediments along strike, rather than an unobserved angular unconformity. The consistency of thinning to the southwest

Table 28. Formational thicknesses along strike (in meters).[1]

Unit	NE	SW
Rancocas Group		
Vincentown Fm.	30	7.5
Hornerstown Fm.	9	6
Subtotal	39	13.5
Monmouth Group		
Tinton Fm.	7.5	0
Red Bank Fm.	34.5	0
Navesink Fm.	10.6	1.5
Mount Laurel Fm.	6	21
Subtotal	58.6	22.5
Matawan Group		
Wenonah Fm.	21	4.5
Marshalltown Fm.	14	4.6
Englishtown Fm.	42	6
Woodbury Fm.	15	0
Merchantville Fm.	12	18
Subtotal	104	33.1
Total	201.6	69.1

[1]Thickness figures compiled from Richards (1956), Olsson (1963), Owens and Sohl (1969), Owens et al. (1970), and Petters (1976).

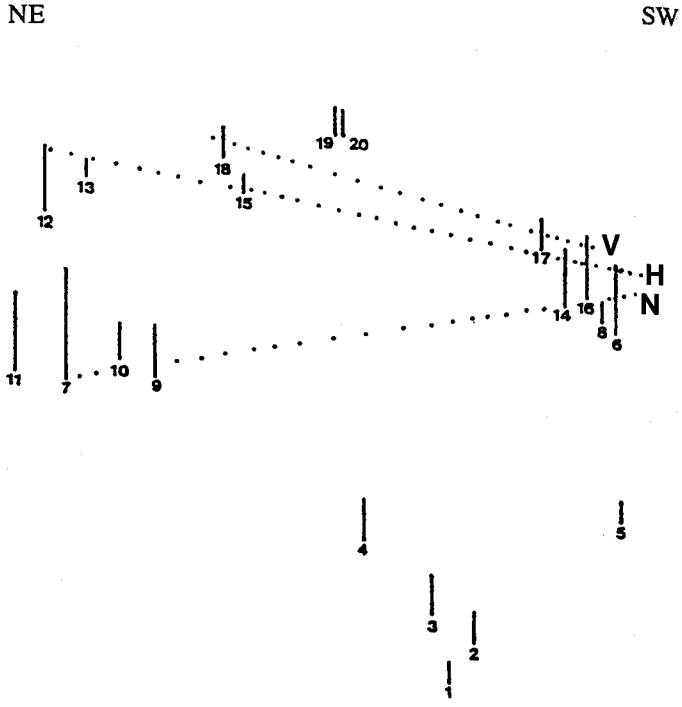


Figure 12. Relative positions of the measured sections from the northeast to southwest, demonstrating thinning of Upper Maastrichtian and Danian units along strike. Diagonal lines represent bases of formations: V = base of Vincentown Formation, H = base of Hornerstown Formation, N = base of Navesink Formation.

seen in most of the formations (see Fig. 12) is thus explainable as the condensation of the section away from the primary source of terrestrial clastic deposition in the northeast, where the Red Bank and Tinton were laid down as nearshore deltaic deposits (Gallagher, 1984; Owens and Gohn, 1985; Gallagher et al., 1986). This is supported by the low sedimentation rate that is generally accepted for glauconite deposition; individual grains may take thousands of years to undergo glauconitization, during which time they must remain at or near the sediment-sea water interface (Odin, 1988). This means that low terrestrial clastic influx is required for glauconite concentration, as well as large amounts of time for the accumulation of even minor thicknesses of greensand; and the purest glauconite deposits, such as the Hornerstown Formation, will require the lowest depositional rates and the most time.

So to the southwest along strike the upper part of the Navesink (which is more clastic, containing more clay and small quartz grains than the upper part of that unit in Monmouth County) represents the same interval as the Red Bank and Tinton Formations in the northeast. This is supported by Koch and Olsson's (1977) observation that microfossil zones under the Hornerstown are the same along strike regardless of the underlying lithology. Generally speaking the contact between the Navesink and the Hornerstown in the southwest is so smeared out by bioturbation that it is frequently indeterminate, as at Section 6 (Appendix). The contact between these two units may be characterized as a disconformity or an omission surface, in the sense of Bromley (1975), where only a minor break in sedimentation is implied and there is little or no erosion involved. The infilling of subjacent burrows into the Navesink with purer greensand of the Hornerstown above suggests that there were no overlying deposits removed, since these would have been preserved in the burrow-infilling material (Bromley, 1975).

Marine Invertebrate Paleoecology

Hansen et al. (1984), Jablonski (1986), Sheehan and Hansen (1986), and Jones et al. (1987) have presented analyses of Gulf Coastal Plain K/T sections that include considerations of the differential survival of marine benthos, principally mollusks, in the mass extinction event at the end of the Mesozoic. Hansen et al. (1984) looked at the Brazos River section, determining that this exposure was a more complete K/T sequence than previously supposed. They noted that typically Cretaceous molluscs persist up to the micropaleontologically-defined K/T boundary, and then are abruptly terminated. Above the boundary, molluscs show a reduction in average body size. The common factor among the disappearing Cretaceous molluscs is that they are mostly suspension-feeders; deposit-feeding nuculanids continue across the boundary relatively unaffected. Their conclusion is that planktonic taxa and those feeding on them were the most drastically affected.

Sheehan and Hansen (1986) went on to expand this idea to include terrestrial ecosystems as well. They proposed that detritus feeding in general, both in marine environments and on land, was a buffer to extinction. In terrestrial environments, the forest soil food chain nourished the K/T survivors such as insectivorous mammals; in the ocean, deposit feeders were favored.

Jablonski (1986) reviewed diversity figures for marine bivalves and gastropods from Gulf and Atlantic Coastal Plain Upper Cretaceous and Tertiary deposits. Significantly,

Jablonski did not look at groups other than pelecypods and gastropods. From these data, Jablonski determined that the only generalization to be made about K/T survivability is that clades with widespread geographic ranges were favored during the K/T mass extinction. This certainly does not seem to have helped the ammonites or exogyrids, whose widespread ranges have made them useful biostratigraphic tools.

Contrasting with the above mentioned studies, the present study demonstrates that the primary determinant of selective survival across the K/T boundary among a wide range of groups (not only molluscs but also brachiopods, bryozoa, sponges, and corals) is non-planktotrophic reproductive strategy, as determined by population percentages derived from outcrop sampling of a succession of fossil assemblages across the K/T boundary. This is not substantially different from Hansen et al.'s (1984) conclusion that planktonic taxa and forms feeding on them were most affected at the K/T boundary.

It should be noted that all of the above-named authors mentioned the possibility of a depositional hiatus at the boundary in their sections, but all were in agreement that such a hiatus in the Coastal Plain was short-lived and did not affect interpretation of the longer-term patterns of survival and extinction. Hallam (1992) cites a number of studies indicating that the latest Maastrichtian regession was short-lived before a transgression set in at the K/T boundary.

Taphonomic Discussion

The Ellisdale Site, in Monmouth County, N.J., provides an interesting contrast to the glauconitic fossil beds, while continuing to produce new and important taxa (Grandstaff et al., 1992). The Ellisdale assemblage of mixed terrestrial, aquatic, estuarine and marine forms is undoubtedly a transported and at least partially reworked association; there are no articulated vertebrate remains from this site, and virtually all of the isolated bones and teeth show some evidence of breakage, wear, or abrasion. This is indicative of a complex history producing a taphonomically mature assemblage. The best explanation would seem to be storm deposition in an estuarine environment; Barron (1989) has suggested that by Late Cretaceous (Campanian-Maastrichtian) time the development of the Atlantic Ocean coupled with Tethyan equatorial circulation could have generated severe storms in this area. Recently, Tashjian and Grandstaff (1990) have presented heavy mineral data showing a prodominantly terrestrial heavy mineral suite in the Englishtown sands underlying the fossiliferous layer at Ellisdale, while coincident with the flat pebble layer there is a "spike" of marine heavy minerals that falls off rapidly. The overlying clays have a terrestrial heavy mineral suite that is gradually replaced upward in the section with increasing amounts of marine heavy minerals. These data are consistent with the model of storm deposition of the Ellisdale taphocoenosis, with a storm surge mixing in marine heavy minerals and marine organic remains into an estuarine depositional environment.

For the basal Hornerstown Main Fossiliferous Layer (MFL), we must turn to the work of Kidwell (1982, 1984, 1985, 1986, 1989) and Kidwell and Jablonski (1983) for a taphonomic model. Studying shellbeds in the Miocene Chesapeake Group of Maryland, Kidwell has investigated the origins of complex fossil concentrations associated with basal discontinuities in sedimentation. She proposes that these beds are not merely erosionally reworked or transported concentrations from older beds but in fact represent condensed sections with time-averaged fossil assemblages that occupy a middle range between unconformities and thick continuous sedimentary records. In this view, while the sequence may be lithostratigraphically starved, it is biostratigraphically complete. Condensed section shellbeds are distinguished by complex internal microstratigraphies demonstrating complex histories of accumulation. Importance is placed on the role of taphonomic feedback, the interaction of living organisms with the hardpart substrate. In this model, the controlling factor is sedimentation rate; high sedimentation rate dilutes hardpart concentration while sediment starvation or bypassing makes skeletal concentrations possible.

Certainly the MFL fits this model. As we have seen, authigenic glauconitic sedimentation is very slow and requires very little clastic input. The microstratigraphy of the MFL is complex, consisting of several assemblages including the basal oyster bed, the marine invertebrate layer and overlying vertebrate remains (see Section 16 in Appendix). Abundant evidence has been presented for a variety of biological interactions with dead hardparts.

It is proposed here that the MFL is a complex condensed section fossil assemblage. As such it contains a time-averaged record of biological events across the K/T boundary. Kidwell (1982, 1989) states that this sort of accumulation contains valuable paleontologic information if addressed in the appropriate fashion. Behrensmeyer (1984) lamented the lack of a mass mortality layer at the K/T boundary, while Behrensmeyer and Kidwell (1985) suggested that increased hardpart supply aided by the activity of scavengers could be theoretically expected; I would like to offer the basal Hornerstown MFL with its scavenged concentration of vertebrate remains as an example of a K/T boundary mass mortality layer.

Analysis of Vertebrate Extinction and Survival Patterns Across the K/T Boundary in New Jersey

The following discussions are supported by data in Tables 9-26.

Chondrichthyes
(See Tables 9-13)

Within the cartiliginious fish, the major change in the fauna is the extinction of such forms as *Hybodus* and *Squalicorax*, and their replacement by more progressive lamnoid types. A more subtle change involves *Scapanorhynchus texanus*, the goblin shark, whose mitsukurinid relatives are found today in deep water (Castro, 1983); in the Upper Cretaceous, until Navesink time early in the Maastrichtian, *S. texanus* was the most common shark tooth in shallow water and estuarine deposits (at the Ellisdale Site, for example; Parris et al., 1987). *Squalicorax* and *Scapanorhynchus* dominate Campanian scrap faunas in the New Jersey Coastal Plain, providing the overwhelming number of vertebrate specimens at some sites (Lauginiger, 1986). But while *Squalicorax* persists to the Lower Hornerstown, *Scapanorhychus* appears to have been displaced offshore into deeper ocean marine waters in the early Maastrichtian. This may be a nektonic example of the pattern observed by Jablonski et al., (1983) in which nearshore benthos expanded into deeper environments during the Late Cretaceous.

A similar pattern is apparent among the chimaerids, which were fairly common components of shallow water faunas in the Campanian and Maastrichtian, but are not as well represented in the Paleocene. Today the ratfishes inhabit deeper waters.

Another factor which may be involved in the chondrichthyan faunal changeover is the restriction of food resources. The typical duraphagous predators of the Late Cretaceous were probably affected by the disappearance of the great oyster banks, as discussed in Section 3. This is essentially a food-chain effect, as the reduction in planktonic biomass at the K/T boundary reverberated through higher trophic levels, eliminating planktotrophic oysters and the duraphagous predators feeding on them. This in turn left those predators not directly dependent on this food-chain as the unaffected survivors. The winners in this case seem to have been the lamnoid sharks, open water pursuit predators that also scavenge for food when necessary. An additional factor in the evolutionary development of large lamnoid sharks such as *Otodus* may have been that the niche of large marine predator was left vacant by the disappearance of the big marine reptiles such as mosasaurs and plesiosaurs, clearing the way for the radiation of Tertiary sharks.

Osteichthyes
(See Tables 14 and 15)

Although the true diversity of bony fish in the Coastal Plain K/T section is uncertain for reasons discussed above, certain patterns correlative to other groups are apparent. Freshwater and anadromous forms apparently survived the mass extinction, but among marine osteichthyans open-water predators (*Xiphactinus audax*, *Enchodus ferox*) were eliminated. Duraphagous predators such as *Anomaeodus phaseolus* and *Paralbula casei* also disappeared, perhaps as a result of the decline of the great Cretaceous oyster banks. It is apparent that the oceanic population of fish must have suffered some effect from the collapse of the plankton-based food chain, and the Fish Clay of Stevns Klint in Denmark may reflect this mass mortality event. It is interesting to note the concentration of fish remains in the basal Hornerstown Formation at Section 15 and 16 in this regard.

Amphibia
(See Table 16)

Amphibian remains have only recently been reported for the first time in New Jersey Upper Cretaceous deposits (Parris and Grandstaff, 1989). Their remains are rare, and presently only known from the Ellisdale Site.

Reptilia: Chelonia
(See Tables 17 and 18)

While terrestrial and freshwater turtles appear to have experienced only minor extinction levels in the K/T interval (Hutchinson and Archibald, 1986), this is not the case among the marine chelonians. Pelomedusids disappear from northern Coastal Plain deposits above the basal Hornerstown Formation MFL, where *Bothremys* and *Taphrospys* are found. *Agomphus* and *Adocus*, representatives of the Dermatemydidae, also drop out at this level, although their fresh-water and estuarine sister group, the trionychids, have survived to the present day. Coupled with the extinction of the protostegids and the near-disappearance of all the toxochelyids in the New Jersey K/T section, the marine turtle extinction represents a major faunal turn-over with only one species out of thirteen Cretaceous taxa continuing above the basal Hornerstown. The sole survivor among the sea turtles is *Osteopygis*, which continues into the Vincentown Formation and on into the Early Eocene Manasquan Formation.

Since there is demonstrable differential survival between terrestrial/freshwater and marine turtles, there would seem to be nothing inherently special about chelonians, such as a supposed evolutionary conservatism, to ensure their continuation across the filter of the K/T boundary. The selection is environmental in nature. Most modern sea turtles are more or less omnivorous, although shellfish form a major part of most species' diets, and a few (such as *Lepidochelys kempii*) are primarily duraphagous predators (Ernst and Barbour, 1972). In addition to whatever physical environmental effects may have swept through the ocean at the end of the Cretaceous, a drop-off in planktonic biomass productivity could also have affected the invertebrate prey of marine turtles, causing their decline through food chain collapse.

Reptilia: Lepidosauria
(See Tables 19 and 20)

True lizards have only recently been recognized in the New Jersey Cretaceous deposits (Parris and Grandstaff, 1989), and the families to which these animals belong are extant. No lizard remains have yet been discovered in Paleocene or Eocene strata in the northern Coastal Plain. The few lizard specimens known are from the Ellisdale local fauna, a unique assemblage with a larger proportion of terrestrial forms than is usually the case in the primarily marine Coastal Plain deposits. The lizard fauna from Ellisdale is currently under study and has yielded a new and as yet undescribed taxon (Denton et al., 1992).

Probably the most common large extinct reptile remains in this area are mosasaurs. The family is represented by nine species in New Jersey (Russell, 1967), six of which are found in the lower Hornerstown Formation. The mosasaurs appear to have survived to the end of the Maastrichtian with little change in diversity, only to vanish abruptly. They were also at their apex in size; Russell (1967) has estimated a length of 12 m (40 feet) for NJSM 11053, a skull of *Mosasaurus maximus* from the middle Navesink Formation at the Inversand Pit (see Section 16 of Appendix). The collections at ANSP, AMNH and YPM contain numerous specimens of mosasaurs excavated from the Maastrichtian strata during the heydey of marl mining in the nineteenth century.

Mosasaurs seem to have been opportunistic predators, taking a wide variety of prey items (Martin and Bjork, 1987). Again, a combination of physical oceanographic changes (e.g., changes in oceanic temperature) and biotic stresses involving food chain disruption seem adequate proximal causes for the extinction of the mosasaurs. Disappearance of prey items such as ammonites, sea turtles and Cretaceous chondrichthyans is consistent with a planktonic food chain collapse mediated to higher trophic levels by the decline of marine invertebrates with planktotrophic larval stages. A similar fate can be supposed for the Upper Cretaceous plesiosaurs, which are far less common as fossils than mosasaurs.

When we look at the record of fossil snakes in the New Jersey K/T section, we see a possible replacement group occupying the niche of large marine predator. Though specimens are rare and generally consist of isolated vertebrae, a total of five species distributed among three genera are found in the later Paleocene and early Eocene deposits. It is suggested here that large marine snakes such as *Paleophis* temporarily filled the niche left vacant by the extinction of mosasaurs and plesiosaurs.

Reptilia: Plesiosauria
(See Table 21)

The record of plesiosaurs is not particularly good in the New Jersey Upper Cretaceous, consisting of a few finds, mostly isolated vertebrae. It would appear that plesiosaurs were a group already on their way out, for they are never as common as the remains of their competitors, the mosasaurs, found in the same marine deposits. Suffice it to say they were part of the fauna affected by the K/T mass extinction event, although probably not an important part.

Reptilia: Crocodylia
(See Table 22)

The studies by Carpenter (1983) and Parris (1986) have served to reduce the oversplit crocodylians to a more manageable number of taxa. In the Campanian, particularly in the basal Marshalltown Formation at Ellisdale (see Section 4), there are a few small alligatorids, a small crocodile, and the giant *Deinosuchus rugosus*. This an an estuarine assemblage, and it is probable that the brackish-water crocodylians contributed to the Ellisdale taphocoenosis by way of their scat (as discussed in Section 4).

The MFL in the basal Hornerstown Formation is the other great source of crocodylian remains in the New Jersey K/T sequence. The evidence for a crocodylian extinction is equivocal. Several alligatorids are present in the MFL, but not in superjacent strata; however, we know the alligators survived. *Thoracosaurus neocesariensis*, a narrow-snouted gavial-like form, is the most widely spread crocodylian of the Maastrichtian-Danian beds, continuing from the Mount Laurel to the Vincentown Formation. The mesosuchian *Hyposaurus rogersii* is characteristic of both the lower and upper parts of the Hornerstown Formation.

In short, there is no convincing evidence of a faunal turnover among the crocodylians at the K/T boundary in this section. Survival of the crocodylians may be attributable to several factors, including:

1) Preferred prey. Modern crocodylians are capable of taking a wide variety of prey items. They are not specialized predators, and need not depend upon shell fish or duraphagous carnivores for their food.

2) Wide range of habitats. Modern crocodylians are euryhaline and can tolerate a wide range of salinities. They may have retreated to brackish or fresh water refugia during the worst of the K/T oceanographic stresses.

3) Size. Even the largest K/T crocodylian (*T. neocesariensis*) is a modest animal when compared to mosasaurs or plesiosaurs. Among the Cretaceous reptiles, the larger forms were selectively extirpated, while smaller animals survived (Dodson and Tatarinov, 1990).

Reptilia: Pterosauria
(See Table 23)

The remains of flying reptiles are extremely rare in the northern Coastal Plain Cretaceous deposits and have only recently been recognized (Baird and Galton, 1981). The stratigraphic distribution of the Ornithocheiridae consists of two points, the early Campanian of Delaware and the early Maastrichtian Navesink Formation of Atlantic Highlands at the extreme northeastern portion of the outcrop belt (see Section 11). This range in space and time suggests that fossils of these animals could be expected in any of the Coastal Plain Cretaceous units, but because of their fragile nature they were probably not preserved very often. Because of this scarcity, there is not much material for evaluation of their extinction pattern, except to note that they were a part of the Cretaceous fauna that became extinct in this area.

Reptilia: Dinosauria
(See Table 24)

While most of the taxa heretofore considered have been aquatic or marine forms, the dinosaurs were terrestrial animals. Thus their distribution in the primarily marine deposits of the New Jersey K/T sequence is rather spotty. However, enough specimens have been recovered to demonstrate a virtually continuous stratigraphic distribution from the Merchantville Formation to the top of the Navesink Formation for the hadrosaurs. NJSM 15136 is an isolated vertebral centrum from the top of the Navesink (Olsson's New Egypt) Formation, about a decimeter below the contact with the overlying Hornerstown. This specimen compares quite closely to YPM 1600, Marsh's type of *Hadrosaurus minor* obtained from about the same stratigraphic level in the West Jersey Marl Company pit nearby in Barnsboro. NJSM 15136 is the stratigraphically highest dinosaur specimen known from the New Jersey Coastal Plain; there are no authenticated and well-documented dinosaur specimens from the basal Hornerstown Formation. Either dinosaurs had all but died out before MFL time, or the MFL was deposited in water depths so distant from the shoreline that floating dinosaur carcasses never made it that far. If the MFL were a reworked assemblage, one would expect it to contain dinosaur remains from the underlying Navesink.

Theropods range from the Marshalltown Formation through to the upper part of the Navesink Formation; and isolated evidence in the Raritan Formation makes it clear that they were present in this area as early as the Cenomanian (Baird, 1989). The most complete skeleton is Cope's type specimen of *Dryptosaurus aquilunguis* from the old pits at Barnsboro; however, isolated bones are still being found today, especially at Big Brook (Section 9) and Ellisdale (Section 4), both in Monmouth County. These specimens are from Late Campanian and Early Maastrichtian deposits: the type of *D. aquilunguis* is probably the highest stratigraphic occurrence of Theropoda in New Jersey.

The stratigraphic range distribution demonstrates that dinosaurs were present and probably common in New Jersey from the early Campanian to late in the Maastrichtian. Hadrosaurs probably inhabited coastal ecosystems where primary productivity was high (Gallagher, 1984; Gallagher et al., 1986); their principal predators were probably large crocodilians (e.g. *Deinosuchus*) and dryptosaurs. Disruption of the productivity of these ecosystems could serve as sufficient cause for extinction of the dinosaurian herbivores and their dependent terrestrial predators. Such a disruption could be caused by climatic fluctuations, such as warmer or cooler phases: Johnson et al. (1989) demonstrated temperature changes in the Western Interior, and other studies have also indicated temperature changes at this time. Reproduction in some reptiles (crocodiles, turtles) is highly temperature dependent (Paladino et al., 1989), with sex determined in the egg by temperature in the nest. Extreme temperature excursion, either colder or warmer, produce hatchlings of a single sex. Furthermore, environmental stress of this sort can lead to egg-shell thinning and embryonic mortality (Erben et al., 1979). While gradual climate change could have led to reproductive failure among the dinosaurs, it is also a postulated consequence of the impact scenario that worldwide

temperature fluctuations would ensue. Cold caused by dust-cloud albedo enhancement would be followed quickly by carbon dioxide-induced greenhouse warm-up causing rapid extremes of temperature, in addition to the other physical stresses associated with a large bolide impact (O'Keefe and Ahrens, 1989).

Aves
(See Table 25)

While fragile and exceedingly rare, enough bird bones have been recovered from the glauconitic deposits of the Navesink and lower Hornerstown Formations to indicate that an avifauna of primitive shorebirds was present in this area in the Maastrichtian. Most of the fossil material is assigned to the Graculavidae, included within the order Charadriiformes; today, the charadriiforms are distributed worldwide around marshes, lakes, beaches, and coastal waters (Austin, 1985). They are a diverse group including snipes, curlews, plovers, sandpipers, and gulls; of these the New Jersey fossils seem most similar to the Burhinidae, or curlews (Olson and Parris, 1987). Preferred food includes aquatic and marine invertebrates and small vertebrates. The graculavids are sufficiently distinct from other charadriiformes to be accorded their own family; in addition, Olson and Parris (1987) have named a new species, *Titthostonyx glauconiticus*, which they assign to a new genus and family within the Procellariiformes (albatrosses, shearwaters, and petrels).

None of these bird remains occur above the basal Hornerstown, but a single record of *Diatryma regens* is known from Lower Eocene deposits of the Manasquan Formation. It would appear that large flightless birds took over the niche of peak predator in the terrestrial food chain after the extinction of the theropods and before the mammalian radiation of carnivores. As for flying birds, migration probably helped them escape the worst of the K/T boundary effects.

Mammalia
(See Table 26)

Probably the most significant new development in the vertebrate paleontology of the New Jersey K/T sequence is the discovery of Cretaceous mammals at Ellisdale (Parris and Grandstaff, 1989; Grandstaff et al., 1992). So far the Ellisdale Site (Section 4) has produced a multituberculate incisor (*Cimolomys clarki*) and a marsupial tooth (*Alphadon lulli*); there is also some indeterminable mammalian material, possibly multituberculate. These specimens re-emphasize the terrestrial aspect of the Ellisdale Site. The only other mammal known from this area is an indeterminate and questionable report from the Mount Laurel Formation (Krause and Baird, 1979). It is too early for analysis of mammalian extinction patterns in the New Jersey K/T sequence; that must await further discoveries.

Geochemical Results

Gallagher (1992) reported on the results of geochemical studies at the K/T section in the Inversand Pit (Section 16). The low values (100-200 ppb) obtained for iridium peaks in the lower Hornerstown Formation samples are still high enough above the background Ir level to stand out as potential enrichment layers; other studies (Johnson et al., 1989) have used the criterion of excursion from background levels to define Ir anomalies. Certainly the factors of bioturbation and bulk sampling must also be taken into account. Given these considerations, the three peak values found in this section can be interpreted either as the results of Ir biogeochemical mobility from an initially restricted layer, or as repeated low fluxes from multiple events such as repeated vulcanism or several bolide impacts. Iridium mobility within igneous rocks has been suggested by Crocket and Kabir (1987), and McLaren (1985) has shown that Ir anomalies at the Frasian-Fammenian mass extinction horizon in Australia are concentrated in bacterial stromatolites. Recently it has been experimentally demonstrated that some marine micro-organisms are capable of mobilizing and concentrating iridium (Dyer et al., 1989). Thus it appears that Ir is more biogeochemically active than once supposed. Crocket et al. (1988) have observed several Ir anomalies in the Gubbio section from 2 m below the K/T boundary and the Alvarez et al. (1980) initial Ir anomaly to 2 m above it; they attribute this more continuous flux to episodic intense vulcanism over a more protracted period of time then called for by catastrophic impact models. Other possible concentrating mechanisms for Ir include metal precipitation from seawater due to reducing conditions, and enrichment of siderophiles by dissolution of carbonates and concentration of meteoritic dust, especially in condensed sections (Ekdale and Bromley, 1984). These conditions may have prevailed in the lower Hornerstown depositional environment.

As part of the Strangelove Ocean scenario, some workers (Hsu et al., 1982) have argued for massive poisoning of the marine biosphere, either by cyanide from a cometary impact or from toxic metals derived from a bolide impact. In the first case, it is highly unlikely that an organic compound like cyanide would survive the extremely destructive pressures and temperatures of an impact. In the second case, toxic metals should be detectable in immediate post-K/T marine sediments where they would be deposited as organic complexes. As the data for the Navesink and Hornerstown indicate (Gallagher, 1992), this hypothesis is not supported by testing for trace mineral differences. Glauconite has a high ion-exchange capacity, and is known to effectively remove heavy metals from landfill leachate (Spoljaric and Crawford, 1979), so this is an especially appropriate test.

Summary

Olsson (1970) has estimated that the Hornerstown Formation was deposited over a period of 4.5 million years, based on microfossil biostratigraphy. This is in essential agreement with the length of Hornerstown time as determined through K/Ar dating by Owens and Sohl (1973). Assuming a relatively constant rate of sedimentation for this homogeneous, nearly pure glauconitic unit, the 5.5 m of Hornerstown greensand exposed at the Inversand Pit (see Section 16) was deposited at the net rate of approximately 1.2 m per million years. This means that the basal 0.3 m of Hornerstown containing the MFL assemblage was deposited over a period of about 250,000 years. This time span is consistent with the long periods required for glauconitization (Odin, 1988) as well as with Kidwell's (1982, 1989) upper estimates for the genesis of complex condensed skeletal concentrations.

Hence, the terminal Mesozoic extinction event in the Coastal Plain deposits of New Jersey cannot be constrained within less than 250,000 years resolution. Given the ambiguous nature of the iridium data and the evidence of gradual diversity reduction among the invertebrates (for example, the ammonites; see Table 7), it would appear that a catastrophic extinction event is not determinable within these deposits. However, major patterns of differential extinction and survival

mong various groups of organisms are determinable and can rovide us with some generalizations about the extinction rocess at this important datum in geologic history.

Among the marine invertebrates there is a selection for non-planktotrophic reproductive strategies in the early Paleocene, while previously abundant forms with planktotrophic larvae suffer reduction of stocks. As a secondary consequence epifaunal suspension feeders briefly flourished in the Danian of New Jersey, forming a paleocommunity that was distinctly Paleozoic in aspect.

There is a clear signal of extinction among marine vertebrate groups not noramlly considered to have been caught up in the K/T event, for example sharks and sea turtles, in addition to the better known victims such as mosasaurs and plesiosaurs. This can be explained as the result of the collapse of the planktonic food chain base mediated to higher trophic levels (e.g., duraphagous carnivores and their predators) via planktotrophic invertebrate mass mortality.

Comparative taphonomy can serve as a powerful tool to discriminate between physically transported, reworked fossil assemblages (for example the Ellisdale Site) and essentially in-place thanatocoenoses that have been subjected to biological modification in conditions of low depositional rates offshore (e.g., the basal Hornerstown MFL). Such discriminatory ability is absolutely crucial when attempting to determine biostratigraphic ranges and paleoecological patterns across a major datum like the K/T boundary.

Finally, we can assess these conclusions within the context f the larger K/T debate. The gradual reduction of some etaceous marine invertebrate stocks can indeed be related more traditional concepts of extinction such as the loss of bitat and climatic changes associated with regression at the d of the Maastrichtian. While some groups, most notably e plankton, have been exemplified as the primary evidence r catastrophic biomass collapse at the K/T boundary, cently (Keller, 1989) even this sudden collapse has been estioned. The Ir anomaly has proven to be more complex n originally depicted, but other substantiating evidence has sen for a major impact event or events at the end of the etaceous, including osmium ratios, shocked quartz grains d other evidence of shock metamorphism, high levels of ot at the iridium layer, microspherules and so-called impact sses, carbonate dissolution and stable isotope excursions. f these, the shock metamorphic features are perhaps most rsuasive. While some have attempted to explain the ocked quartz grains at the K/T boundary as the product of lcanic activity (Officer et al., 1987), other workers have uted this notion (Alexopoulos et al., 1988; Sharpton and hurayz, 1989). Moreover, long before this debate began ock metamorphism was accepted as definitive proof of pact-level hyper-pressures (Short, 1966). Recent develop-nts in the Caribbean region have identified a buried K/T ter and linked it to impact glass and suspected impact nami deposits (Hildebrand et al., 1991; Smit et al., 1992; arez et al., 1992).

While a number of authors (Archibald and Clemens, 1982; nley, 1984; Officer and Drake, 1985; Officer et al., 1987; Hallam, 1987; among others) have argued that the fossil ord displays a gradual dwindling of the final Cretaceous ms and hence refutes catastrophic models for the K/T extinction, the limits of paleontological resolution are in most instances not fine enough to distinguish between days, years, or millenia. The physical evidence for a large-scale impact at the K/T boundary is mounting, and it may be long past time to abandon the absolute dichotomy that forces us into the logical fallacy of either/or thinking. Taking into account all the available evidence, it is submitted here that during a time of ecologically disruptive environmental change, a large impact or series of impacts supplied the final impetus for the extinction of the dinosaurs and many other organisms experiencing an evolutionary bottleneck. In the case of the dinosaurs the extinction process may have been linked to reproduction; certainly, as Pimm et al. (1989) have suggested, large body size is linked to low reproductive rates and proneness to extinction in modern vertebrates. Reproductive strategy among the marine invertebrates also seems to have been critical. The initial hypothesis of dust cloud termination of photosynthesis seems too weak and unsupportable at this point; it is contradicted by the simple fact that in polar regions today the planktonic biomass experiences several months of darkness every year and still provides some of the richest feeding areas in the sea for large cetaceans. Moreover, planktonic biomass productivity was suppressed for at least several hundred thousand years after the K/T boundary, and full return to pre-K/T diversity took even longer (Keller, 1989). This could be the product of a series of cascading effects resulting from an impact, including:

1) Cooling climate from the blocking of sunlight, followed by:
2) Carbon dioxide warming (O'Keefe and Ahrens, 1989) lasting from centuries to millenia. Sources of CO_2 would include:
   a) the impact itself, if the bolide hit major carbonate depoists;
   b) wildfire injection of CO_2;
   c) planktonic die-off would reduce one sink, decreasing drawdown from the atmosphere.
3) Acid rain produced by wildfire-generated NOx and SOx would lower the pH of oceanic surface waters and dissolve carbonate plankton tests.
4) Depletion of atmospheric ozone could cause prolonged extinctions (Gallagher, 1989a, 1990a, 1992). This would take place in three stages:
   a) initial puncturing of the atmosphere by the mass of the bolide, creating a hole in the O_3 layer;
   b) fireball thermal dissociation of O_3, widening the hole;
   c) injection into the atmosphere of large amounts of NOx and SOx from the impact and from wildfires would further corrode the O_3 layer.

Starley Thompson (personal communication, 21 July 1989) has run computer simulations that indicate that a 10 km bolide impact would eliminate between 90% and 99% of the earth's ozone layer. Laboratory experiments have demonstrated that increased ultraviolet radiation can adversely affect the photosynthetic process in phytoplankton, and high levels of UV cause plankton mortality (El Sayed, 1988). More recently, field studies have revealed a variety of adverse effects of ozone depletion on Antarctic phytoplankton (Smith et al, 1992).

All of this, coupled with gradual terrestrially-driven changes in climate, atmospheric composition and oceanographic conditions seems adequate to account for a protracted period of extinctions punctuated by a major catastrophic event

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Finally, we can assess these conclusions within the context of the larger K/T debate. The gradual reduction of some Cretaceous marine invertebrate stocks can indeed be related to more traditional concepts of extinction such as the loss of habitat and climatic changes associated with regression at the end of the Maastrichtian. While some groups, most notably the plankton, have been exemplified as the primary evidence for catastrophic biomass collapse at the K/T boundary, recently (Keller, 1989) even this sudden collapse has been questioned. The Ir anomaly has proven to be more complex than originally depicted, but other substantiating evidence has arisen for a major impact event or events at the end of the Cretaceous, including osmium ratios, shocked quartz grains and other evidence of shock metamorphism, high levels of soot at the iridium layer, microspherules and so-called impact glasses, carbonate dissolution and stable isotope excursions. Of these, the shock metamorphic features are perhaps most persuasive. While some have attempted to explain the shocked quartz grains at the K/T boundary as the product of volcanic activity (Officer et al., 1987), other workers have refuted this notion (Alexopoulos et al., 1988; Sharpton and Schuraytz, 1989). Moreover, long before this debate began shock metamorphism was accepted as definitive proof of impact-level hyper-pressures (Short, 1966). Recent developments in the Caribbean region have identified a buried K/T crater and linked it to impact glass and suspected impact tsunami deposits (Hildebrand et al., 1991; Smit et al., 1992; Alvarez et al., 1992).

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All of this, coupled with gradual terrestrially-driven changes in climate, atmospheric composition and oceanographic conditions seems adequate to account for a protracted period of extinctions punctuated by a major catastrophic event

and a subsequent suppression of biomass productivity in the early Paleocene.

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APPENDIX
STRATIGRAPHIC SECTIONS

Explanation and Keys

Certain conventions of stratigraphic description have been followed in this Appendix. All measurements are in meters. Color codes refer to the system used in the Geological Society of America Rock Color Chart. The illustrated columnar sections (which appear at the end of the Appendix) use standardized symbols for lithologic and faunal components, as depicted on the keys in Fig. A-1 (following the descriptions).

Section 1. Railroad Cut between Camden Avenue and Church Road, Merchantville, Camden County, N.J. (Camden, N.J., quadrangle)

When this cut was first excavated for a Pennsylvania Railroad right-of-way in 1896, it produced a hadrosaur metatarsal which Cope identified as *Ornithotarsus immanis*, largely on the basis of its large size (Woolman, 1896). A few feet below the stratigraphic horizon which produced the dinosaur bone, a "black clay marl" yielded a marine fauna of bivalves, gastropods, and ammonites, the latter group consisting of *Placenticeras placenta* (DeKay), *Menabites delawarensis* (Morton), *Scaphities hippocrepis* DeKay, and *Baculites ovatus* Say. The first three forms are characteristic zone fossils for the Merchantville Formation. The dinosaur bone is ANSP 8956 and is attributed to the Merchantville Formation. However, Woolman's (1896) original description of the stratigraphic position of the bone as being from "iron, brown and mottled yellow clay" combined with a careful look at the stratigraphy of the site as it is exposed at present make it probable that this specimen is actually from the Woodbury Formation, the same unit as the type specimen of *Hadrosaurus foulkii* Leidy, found nearby in Haddonfield (see Section 2). A description of the railroad cut exposure follows (reading upward in section):

Description	Thickness	Total
Base of exposure to base of nodule layer. Greenish-black (5 G 2/1) clayey glauconitic very fine to fine sand.	0.90 m	0.9 m
Siderite nodule layer; concretions in fine sand matrix.	0.10	1.0
Mottled greenish-black (5 GY 2/1) silty micaceous clay weathering to dark yellowish-orange (10 YR 6/6) limonitic crust.	1.5	2.5
Dark gray (N3) silty micaceous clay with blocky weathering.	1.0	3.5
Light brown (5 YR 6/4 to 5 YR 5/6) clayey fine sand and gravel.	2.0	5.5
Soil, disturbed in places.	1.0	6.5

It is equally apparent, from this description, that the basal greenish-black clayey fine sand capped by the siderite concretion layer is the Merchantville Formation; this corresponds to the "black clay marl" that proudced the marine fauna, including the typical Merchantville ammonite assemblage. It is equally clear that the overlying heavily mottled limonitic clay is equivalent to the "iron, brown and yellow-mottled clay" described by Woolman (1896) as the source of ANSP 8956. Above this the blocky dark gray micaceous clay is undoubtedly the Woodbury Formation. The layer from which ANSP 8596 came seems more closely related lithologically to the Woodbury; it is, for example, more a clay than a fine sand, and it is more grayish in hue than the Merchantville. While the relationship between the two units has been described as gradational (Richards, 1956; Owens and Sohl, 1969), the siderite concretion layer seems a convenient place to draw a boundary, since an abundance of such nodules is a characteristic of the Merchantville (Owens and Sohl, 1969; Gallagher, 1984). Moreover, the limonitic mottling in the dinosaur bone horizon may be the product of precipitation of iron due to compositionally-controlled permeabililty differences; such layers are common in other formation-boundary sections in the New Jersey Coastal Plain (Gallagher, 1984).

Section 2. Hadrosaurus Run, Maple Avenue, Haddonfield, Camden County, N.J. (Camden, N.J., quadrangle)

Exposures of the Woodbury Formation are observable less than one-quarter mile upstream from the site of the discovery of *Hadrosaurus foulkii* Leidy in 1858. Several years ago excavations for a new sewer line were dug right over the area of the *H. foulkii* dig. With Leidy's map in hand, I walked this excavation to discover, if possible, the fate of the original *H. foulkii* pit. It soon became apparent that the original site had been landfilled some time ago, judging from the antique glass items. Fortunately undisturbed exposures of essentially the same section are

available only a short distance upstream. Since a formal stratigraphic description and illustrated section have never been presented for this historic locality, it is fitting to include one here as an example of the typical Woodbury Formation (reading upward in section).

Description	Thickness	Total
Dark gray (N3) silty micaceous clay, weathering to blocky fracture, with pale brown (5 YR 5/2) surface; fossils abundant, burrowed at base.	ca 1.5 m	ca 1.5 m
Dark gray (N3) silty micaceous clay, fossils absent, tongues of gravel at top.	2.0	3.5
Dark yellowish orange (10 YR 6/6) clay, irregular boundary at base.	0.20	3.7
Light brown (5 YR 5/6) to dark yellowish orange (10 YR 6/6) coarse sand and gravel.	0.30	4.0
Medium light gray (N6) silty fine sand with small quartz pebbles grading upward into yellowish gray (5 Y 7/1) to light olive gray (5 Y 5/2) medium quartz sand with lenses of gravel soil at top.	ca 1.5	5.5

From the original description (Leidy, 1858) it is obvious that *Hadrosaurus foulkii* came from the upper portion of the basal shellbed at this locality. It should be remembered that in this original description, John Hopkins, the owner of the property and the man who told William Parker Foulke of the extistence of large bones in the area, stated that in the first discovery 20 years previous to 1858, a number of the bones (probably vertebrae but also perhaps a shoulder blade) were carried off by curious visitors. This means that initially *H. foulkii* was a more complete skeleton than the material subsequently excavated by Foulke and preserved as ANSP 10005, consisting of 29 bones, 8 teeth, and associated fragments. Taking this into account, it is apparent that *H. foulkii* was probably a fairly complete carcass that drifted into the marine environment and sank into a low-energy depositional setting; it may have also been scavenged somewhat, since shark (*Scapanorhyncus texanus*) and carnivorous teleost (*Enchodus* sp.) teeth were found closely associated with the dinosaur remains (Leidy, 1858). ANSP 10005 is probably the best example of a taphonomically immature bloat-and-float specimen (as conceived by Dodson, 1971) that the New Jersey Cretaceous section has produced.

The dark gray clay at this site is properly assigned to the Woodbury Formation. The overlying sands and gravels are probably the basal portion of the Englishtown Formation. The Merchantville-Woodbury-Englishtown represent one transgressive-regressive cycle.

Section 3. Big Bend of Rancocas Creek, South Branch, Rancocas Woods State Park, Mount Laurel, Burlington County, N.J. (Mount Holly, N.J., quadrangle)

Just northwest of Hainesport and approximately one kilometer (0.75 mile) upstream from the confluence of the north and south branches of Rancocas Creek, the south branch of the creek makes a wide turn around resistant strata of the Englishtown Formation. The point formed by this turn supports a hill with a low cliff of sandstone, an unusual feature in the largely unconsolidated Coastal Plain sediments. At the base of the section, exposed only at low tide, one can see the dark clay of the Woodbury Formation under the rooted bench of the bank. Above it, the Englishtown sand is apparent, with several indurated layers forming ledges. A measured section description follows (reading upward in section):

Description	Thickness	Total
Dark gray (N3) micaceous silty clay.	0.5 m	– 0.5 m
(Contact obscured by vegetation.)		
Medium to coarse subangular to subrounded feldspathic quartz sand, light brown (5 YR 5/6), massive, moderately sorted.	0.5	0.5
Well-stratified, indurated, medium, subangular to subrounded feldspathic quartz sandstone, moderate reddish brown (10 R 4/6), moderately sorted.	0.2	0.7
Medium to coarse subangular to subrounded feldspathic quartz sand, light brown (5 YR 5/6) to dark yellowish orange (10 YR 6/6) at top; capped by bench; massive.	0.8	1.5
Medium to very coarse subangular to subrounded feldspathic quartz sand with quartz granules, light brown (5 YR 5/6), poorly sorted, massive.	1.2	2.7

Indurated, coarse, subangular to subrounded quartz sandstone, moderate reddish brown (10 R 4/6), well-sorted, massive.	0.6	3.3
Medium to coarse, subangular to subrounded feldspathic quartz sand, light brown (5 YR 5/6), moderately to poorly sorted, massive.	1.3	4.5
Medium to very coarse, subangular to subrounded indurated feldspathic quartz sandstone with quartz granules and small quartz pebbles, light brown (5 YR 5/6) to blackish red (5 R 2/2), wavily laminated with some cross-bedding (10° to 25°, dipping NE), poorly sorted.	3.0	7.6
"Salt and pepper" fine to medium, subangular to subrounded feldspathic quartz sand, medium gray (N5) to light gray (N7), moderately to well sorted, massive; visible glauconite and heavy-mineral grains.	0.5	8.1

Although Reed (1960) and Owens and Sohl (1969) favored a near-shore marine origin for the bulk of the "salt and pepper" sand which underlies large areas of tableland in the Englishtown outcrop belt (for instance in the area between Mount Holly and Moorestown), they also recognized that the locally indurated cross-bedded sands represented a different environment of deposition. These strata are coarser, less sorted and the crossbeds more steeply inclined than one would expect of beach sands or near-shore shallow subtidal deposits. It is probable that the iron oxide-cemented coarser crossbedded strata are fluvial in origin, and that the entire Englishtown is a complex of facies representing regressive sand sheet, fluvial estuarine and lagoonal environments. Unfortunately, the entire formation here is devoid of megafossils in outcrop, although a few burrows may be of marine organisms (Owens and Sohl, 1969). Even the microfossils are sparse, consisting of a low-diversity benthonic foraminifera fauna that is sporadic in occurrence (Petters, 1976).

Section 4. "Bobs Run," Tributary to Crosswicks Creek, Ellisdale, Upper Freehold Township, Monmouth County, N.J. (Allentown, N.J., quadrangle)

As part of the grant to NJSM from the National Geographic Society, a measured stratigraphic section with description was produced by Gallagher and E. E. Spamer for the first NGS report on the Ellisdale site (Parris et al., 1987); much of the formal description given here is adapted from that work. This locality is discussed at length in part 4 of the present paper; here is the description of the sections that, taken together, provide much of the evidence for the interpretations offered in the text (reading upward in section).

Bobs Run, Section A. Immediately downstream from Bobs Run delta, in south bank of Crosswicks Creek

Description	Thickness	Total
At creek level: Glauconitic sand with "cream cheese" mottling and lignite, pale green (10 G 6/2).		0. m
Massive clay with abundant lignite, dark gray (N3).	0.1 m	0.1
Glauconite sand with lignite, light greenish gray (5 G 8/1).	0.1	0.2
Massive clay with glauconitic sand blebs, "cream cheese" mottling, and lignite; dark gray (N3).	0.1	0.3
Medium sand, iron-stained, moderate reddish brown (10 R 4/6).	0.3	0.6
Indurated claystone with lignite, undulating, light brown (5 YR 6/4).	0.1	0.7
Bed varying from 0.7 to 0.9 m thick, medium sand with thin interbedded clays, crossbedded (dip 8° W 270°), variegated in color from iron-stained moderate reddish brown (10 R 4/6) to dark gray (N3); upper surface sloping, irregular.	ca 0.8	1.6
Bed varying from 0.1 to 0.2 m thick, wavily bedded, irregularly interfingering clay and sand, variable in color, dark gray (N3) to light brown (5 YR 6/4).	ca 0.15	1.8
Iron oxide-cemented medium to fine angular to sub-rounded sandstone with flat sideritized mudstone clasts, dark yellowish orange (10 YR 6/6) to moderate reddish brown (10 R 4/6); dipping 7° E, varying in thickness.	0.05	1.85

Massive lignitic micaceous clay, medium light gray (N6) to dark gray (N3) with pieces of lignitic wood at base; at top with irregularly indurated sand laminae, light greenish gray (5 G 8/1) in color.	1.15	3.0

Bobs Run, Section B. Quarry B

Stream level: First flat-pebble layer; massive clay, dark gray (N3).	0.14	0.14
Second flat-pebble layer.	0.01	0.15
Massive clay, dark gray (N3).	0.09	0.24
Third flat-pebble layer with bone, teeth and abundant lignite toward top; variegated color.	0.04	0.28
Medium sand, lignitic at base.	0.12	0.4
Fourth flat-pebble layer with abundant lignite.	0.04	0.44
Massive to wavily bedded clay, sandy at base and with occasional micaceous quartz sand laminae, dark gray (N3); several siderite nodule layers, and lignitic laminae.	1.0	1.44
Medium quartz sand, micaceous, lignitic; some low-angle cross-laminations, lignite log in situ; dusky yellow green (5 GY 5/3).	0.1	1.54
Interbedded clay with sand, irregularly bedded with some flat claystone nodules, mostly dark gray (N3) in color.	0.28	1.82
Medium micaceous clayey sand with siderite nodule layer, upper surface irregular, dusky yellow green (5 GY 5/3).	0.08	1.9
Irregularly bedded clay, dark gray (N3).	0.1	2.0
Medium quartz sand; large siderite nodule with pyrite and lignitic wood; pale green (10 G 6/2).	0.04	2.04
Flaser bedded alternating and intercalated clay and very micaceous silty sandy clay, with IHS (Inclined Heterogeneous Strata) consisting of crosslaminated interbedded sand and clay, predominantly grayish green (10 G 4/2 to 10 G 5/2).	0.3	2.34
Micaceous sandy clay, grayish green (10 GY 5/2).	0.02	2.36
Slightly micaceous medium quartz sand, with wavy clay layers at top, irregular upper surface, light brown (5 YR 5/5).	0.05	2.41
Sandy clay, dark greenish gray (5 GY 4/1).	0.07	2.48
Mottled clayey sand with flat siderite concretions, dusky green (5 G 3/2); upper relations obscured by soil slump.	0.2	2.68

Bobs Run, Section C. Section 2, cliff opposite Large Excavation site

Base of section obscured by groundwater-saturated slump.		0. m
Massive clay, medium dark gray (N4).	0.1 m	0.1
Fine to medium massive quartz sand, lignitic toward top; dark greenish gray (5 G 4/1).	0.4	0.5
Thin bed of greasy micaceous clay with sand stringers, dark gray (N3), variable in thickness.	ca 0.02	0.52
Bed varies from 0.3 to 0.4 m in thickness; micaceous sand, yellowish gray (5 Y 7/2), interbedded with clay pods and lenses, dark gray (N3 to N4) containing rip-up clasts.	ca 0.35	to 0.8

Intercalated sand and clay predominantly dark gray (N3), flaser bedded with rip-up clasts.	0.05	0.85
Iron-stained fine to medium quartz sand, moderate reddish brown (10 R 4/6), with rip-up clasts and thin beds (<2 cm) of greasy clay, dark gray (N3).	0.3	1.15
Intercalated quartz sand and greasy clay, yellowish gray (5 Y 7/2) to dark gray (N3), variable in thickness.	0.15	1.3
Intercalated sandy clay, massive clay, sand with clay stringers, medium gray (N4) to black (N1).	0.22	1.52
Tangentially cross-bedded quartz sand and clay (IHS), light gray (N7) to grayish black (N2).	0.2	1.72
Intercalated sand and clay with lignite, cross-laminations at top, medium gray (N5) to light gray (N7), variable in thickness, clay at top.	0.14	1.86
Iron-stained quartz sand and clay, with pebbles, mottled by modern bioturbation, yellowish gray (5 Y 7/2) to black (N1); top obscured by soil.	0.3	2.16

Bobs Run, Section D. Upper cliff section, above Large Excavation site

Massive clayey glauconitic fine sand, mottling increasing upward; indurated limonite layer at base, mica increasing in top part; dark gray (N3) to medium gray (N5).	3.2 m	3.2 m
Slightly micaceous poorly sorted clayey quartz sand with several pebble layers, including basal pebble layer; greenish gray (5 GY 6/1), mottled; grades into modern soil horizon at top of cliff.	2.4	5.6

Sediment samples from all lithologic units keyed to the NGS report (Parris et al., 1987) sections are deposited at NJSM.

Section 5. Weller's "Lost Locality" at Swedesboro, Gloucester County, N.J. (Woodstown, N.J., quadrangle)

In Weller's (1907) monograph of New Jersey Cretaceous invertebrate fossils, the Marshalltown fauna was represented by an assemblage from one locality, decribed as "one mile a little south of west from Swedesboro . . . in the banks of the brook in the woods . . . ." This site has remained unstudied since that time, largely because subsequent investigators were unable to relocate it (Richards, 1956; Richards et al., 1958). Recently, through the diligence of amateur paleontologists, the exposure has been rediscovered, and the New Jersey State Museum has obtained a number of specimens from this outcrop. A detailed stratigraphic description has never been offered for this site, so I have included a section description here (reading upward in section).

Description	Thickness	Total
Well to moderately sorted clayey quartzose glauconitic fine sand, mollusk shells scattered throughout, but prominent shell beds at 43 cm and 1.3 m; olive gray (5 Y 3/2) mottled with greenish black (5 GY 4/1).	1.5 m	1.5 m
Clay increases upward through gradational contact; concretionary layer containing abundant fossils, usually mollusk shells as steinkerns or in concretions, especially in lower 30 cm; dark yellowish brown (10 YR 4/2) with modeate reddish brown (10 R 4/6) mottles.	0.5	2.0
Silty clay, dark yellowish orange (10 YR 6/6) to light brown (5 YR 5/6), grading upward into clayey fine sand, light olive brown (5 Y 5/6) with light brown mottles (5 YR 5/6).	0.5	2.5
Modern soil with root system.	0.5	3.0

The lower 1.5 meters is the Marshalltown Formation, and at this section it is particularly rich in large oyster shells. Espcially abundant are the species *Exogyra ponderosa* and *Pycnodonte convexa*; smaller oysters such as *Agerostrea falacata*, *Gryphaeostrea vomer*, and *Ostrea panda* are also common. In the shellbed at the top of the Marshalltown, one can see complete articulated oyster shells in life position: gaping but articulated individuals, single valves, and broken shells. This sort of assemblage is similar to those described by Kidwell (1989) in the Chesapeake

Group of Maryland. She ascribes these shellbeds to a complex taphonomic history in a sediment-starved environment. One factor which probably played a part is what Kidwell and Jablonski (1983) called taphonomic feedback, specifically the habit of oysters of congregating and growing on other oyster shells.

This vicinity produced some interesting vertebrate remains. ANSP 10001 and 10002 were located in separate cabinets in the Academy's collection; when I put the two back together, they formed a bone of truly impressive proportions: the proximal end of a hadrosaur left femur with a shaft circumference of 60 cm. There is a third piece of this bone, listed in the Academy's catalog as 10000, but I was unable to locate it. All three are from "the Marl of New Jersey—Swedesboro." In addition, YPM 1587 (fragment of a femur) and PU 22430 (a left phalanx II-2) are from the vicinity of Swedesboro. Both of these specimens are hadrosaurs.

Section 6. Mullica Hill Pond Municipal Park, Mullica Hill, Gloucester County, N.J. (Pitman West, N.J., quadrangle)

This is a classic site that has produced specimens for over a century. In the slopes of the hill just south of Route 222, above the pond, and especially in a gulley carved by an east-flowing tributary to the pond east of Route 45, the following section can be observed (reading upward in section):

Description	Thickness	Total
Medum to coarse quartz sand, with some small quartz pebbles, pale yellowish orange (10 YR 8/6) to moderate reddish brown (10 R 4/6), molluscan steinkerns common toward top.	7. m	7. m
Semi-indurated glauconitic sandy clay with abundant limonitic molluscan steinkerns (*Pycnodonte*, *Agerostrea*, *Cucullaea*, *Anchura*), brownish black (5 YR 2/1) to olive black (5 Y 2/1) with streaks of very dark red (5 R 2/6).	1.	8.
Very clayey fine glauconitic sand, with indurated layer of oyster shells at 8.7 m, dusky yellow green (5 GY 5/2) to grayish olive green (5 GY 3/2).	1.	9.
Clayey fine to medium glauconitic sand, greenish black (5 G 2/1) grading upward into sandy glauconitic clay, dark yellowish brown (10 YR 4/2) burrow mottled with greenish black (5 GY 2/1) glauconite; contact with overlying unit gradational.	3.9	12.9
Clayey fine to medium glauconite sand (greensand), shellbed of *Pycnodonte dissimilaris* at 13.1 m, grayish olive green (5 GY 3/2) in color; top of section obscured by soil and slump.	0.6	13.5

This locality has been historically an important source of invertebrate and vertebrate fossils for several museums. There are, for example, some 65 species of marine invertebrates from this site in the collections of the ANSP. A number of shark tooth specimens recorded from this vicinity are also at ANSP. Some species, such as *Isurus desorii*, *Carcharodon auriculatus*, and *Hemipristis serra*, are too young for this outcrop, and are more likely from lower or middle Tertiary deposits in the area. Since most were collected in the nineteenth century before modern stratigraphic nomenclature was stabilized, accurate stratigraphic data is lacking. Other chondrichthyan taxa are consistent with the age of the exposure described here; these include *Scapanorhyncus* [*Lamna*] *texanus*, *Odontaspis elegans*, *Squalicorax kaupi* and *S. pristodontus*. Among the Reptilia, turtles are represented by *Taphrosphys sulcatus* (ANSP 9666-8) and *Adocus beatus* (ANSP 9184). *Crocodylus* sp. (ANSP 9176-9181) is probably *Thoracosaurus neocesariensis*, as are AMNH 2209 (*Holopsisuchus glyptodon*) and AMNH 2890 (*H. obscurus*). AMNH 2890 is attributed to the Hornerstown Formation, and it is likely that the other reptiles mentioned above came from this horizon; the Hornerstown was dug for marl in this area. Finally, there is YPM 1593, a single posterior dorsal centrum attributed to *Hadrosaurus minor*, probably from the Navesink Formation.

Section. 7. Pit behind Aberdeen Academy of Gymnastics, East of Route 34, Matawan, Monmouth County, N.J. (Keyport, N.J., quadrangle)

This is one of the most complete exposures of the Maastrichtian sequence in Monmouth County, and it yields fossils from several formations in this section (reading upward in section):

Description	Thickness	Total
At base, clayey lignitic micaceous fine quartz sand with some quartz pebbles, thoroughly burrowed, grayish yellow (5 Y 7/6) stained to moderate reddish brown (10 R 4/6), burrow mottled to pale yellowish brown (10 YR 6/2) with occasional lenses of micaceous glauconitic clay; grading upward to micaceous	1.5 m	1.5 m

slightly glauconitic medium to coarse poorly sorted quartz sand with quartz granules, quartz pebbles and siderite flat pebbles, especially concentrated about 1 m above base, thoroughly burrowed, dark yellowish orange (10 YR 6/6), burrow mottled to pale yellowish orange (10 YR 6/2); sharks teeth, bone fragments, and microvertebrates common in places in upper 0.4 m, especially near overlying contact.		
Iron oxide-cemented indurated layer, sandy, glauconitic, light brown (5 YR 5/6).	0.1	1.6
Massive clayey glauconitic fine to medium sand with quartz grains, burrowed, olive black (5 Y 2/1) to greenish black (5 G 2/1); basal 0.6 m contains abundant molluscan steinkerns, *Callianassa* claws, and sharks' teeth; about 3 m above contact with underlying unit there is an oyster shell ghost layer that also contains other molluscan steinkerns.	3.9	5.5
Iron oxide-cemented indurated layer, sandy, silty, moderate reddish brown (10 R 4/6).	0.5	6.0
Massive clayey micaceous sparingly glauconitic fine sand, dark gray (N3) to dusky brown (5 YR 2/2), mottled with dark yellowish orange (10 YR 6/6) in patches; rare sharks' teeth in basal meter.	9.5	15.5
Massive clayey micaceous medium quartz sand, dark yellowish orange (10 YR 6/6).	6.5	22.0

The basal quartz sand with its chaotic texture and vertebrate fossils concentrated near the top is the Mount Laurel Formation, while the overlying glauconitic unit is the Navesink (Gallagher, 1984). Olsson (1963) divided the Red Bank Formation into two members, the Sandy Hook Member and the Shrewsbury Member; both are represented here. The dark gray fine sand above the Navesink is the Sandy Hook Member, while the overlying orange quartz sand is the Shrewsbury.

Krinsley and Schneck (1964) noted the presence of abundant *Callianassa* claws at the contact between the Mount Laurel and Navesink Formations in Monmouth County, and in conjunction with textural features of the coarse sand, interpreted this as evidence of shoaling and perhaps a discontinuity in sedimentation. The common presence of *C. mortoni* claws at the top of the Mount Laurel and in the base of the Navesink at this section may be linked to the extensive *Ophiomorpha*-style burrowing that is apparent in the Mount Laurel Formation. The fragmentary vertebrates along with the poorly-sorted pebbly sands with chaotic fabric and siderite flat pebbles could represent storm lags in near-shore or shore-face environments in the uppermost part of the Mount Laurel. The basal fossiliferous layer of the Navesink is probably a condensed-bed shell deposit; by all indications glauconitic sedimentation in the Navesink was at a slow rate (Krinsley and Schneck, 1964) and while there may have been some reworking, it should be pointed out that the fauna of the basal Navesink is distinctly unrelated to the fossils occurring in the underlying Mount Laurel, and is more closely allied to the shellbed found some 3 meters above the bottom contact.

Finally, the only megafossils apparent in the Red Bank Formation were found only in the basal meter of the Sandy Hook Member, and these consisted of a few broken and bleached sharks' teeth. Above this there were no apparent megafossil concentrations observed, although elsewhere the Sandy Hook Member is said to contain marine invertebrates.

Olsson (1975) has interpreted this sequence as a regressive-transgressive-regressive cycle, with the Mount Laurel representing an innermost shelf shoreface environment, the Navesink maximum transgression, and the Red Bank a regressive inner shelf environment.

Section 8. Chestnut Branch of Mantua Creek, Between Sewell and Barnsboro, Mantua Township, Gloucester County, N.J. (Woodbury, N.J., quadrangle)

Along the banks of Chestnut Branch, a series of outcrops expose several closely packed shellbeds. At Sewell, excavations near the Main Street bridge over Chestnut Branch exposed the Mount Laurel Formation, while just to the southeast streambank and streambed exposures reveal the basal shellbed of the Navesink Formation. Upstream, the upper part of the Navesink is exposed with abundant molluscan fossils in place at the Route 553 (Alternate) bridge just south of Barnsboro. A composite section along this creek is described (reading upward in section):

Description	Thickness	Total
(Basal relations obscured by stream.)		
Very fine to medium quartz sand, slightly clayey, yellowish gray (5 Y 7/2), with abundant *Exogyra cancellata*, *E. costata*, *Trachycardium eufaulensis* and *Belemnitella americana*.	0.5 m	0.5 m
Iron oxide-cemented fine to coarse glauconitic sandstone with quartz granules, dusky yellow green (5 GY 5/2) to grayish olive green (5 GY 3/2) with streaks of moderate reddish orange (10 R 6/6); shellbed with *Exogyra costata*, *Pycnodonte convexa*, *Gryphaeostrea vomer*, and *Belemnitella americana* at base; second shellbed 1.5 m above base of unit with *E. costata*, *P. convexa*, *G. vomer*, *Agerostrea mesenterica*, *Veniella*, *Lima*, *Cucullaea*, *Turitella* cf. *vertebroides*, *Gyrodes*, *Anchura*, and *Baculites ovatus*.	1.5	2.0
Fine to medium grained glauconitic sand, greenish black (5 G 2/1), upper relations obscured by soil and slump.	2.	4.

The indurated shellbed is the base of the Navesink Formation; this was established by Knapp (writing in Weller, 1907) when he used this stratum to clear up some of the confusion surrounding the precise stratigraphic relationships of the Upper Cretaceous sequence and formalize the modern stratigraphic nomenclature for these beds in the process. Knapp showed that the "Lower Marl" (Navesink) had been incorrectly correlated with the glauconitic facies of the Marshalltown Formation, and demonstrated the true nature of the various lithologic changes along strike.

It was from this vicinity that Cope obtained the type specimen of *Dryptosaurus* [*Laelaps*] *aquilunguis* (ANSP 9995 and 10006; possibly also AMNH 2438). Cope (1866) described the dinosaur bones as having come from the West Jersey Marl Company's pits south of Barnsboro, N.J., where they were found in the "chocolate bed, which is of such value as a manure." It is apparent from this description that Cope is referring to the upper part of the Navesink Formation. Moreover, Cope states that they were associated with specimens of *Cucullaea* and *Baculites* sp., generally more common in this area in the top shellbed and above it in the Navesink. Cope also notes the occurrence of a *Hadrosaurus* femur nearby; this is ANSP 10007, a right femur lacking the proximal end. In addition, Marsh obtained YPM 745 (partial left and right tibia, distal end of femur, rib), YPM 3216 (radius and ulna), YPM 7896 (left femur, tibia, distal end of fibula, astragalus, and associated fragments) and YPM 7898 (a left coracoid) from the Barnsboro pits. All are hadrosaurian, and all are from the Navesink Formation.

Section. 9. Cliff downstream from Boundary Road bridge, Big Brook, Colts Neck, Monmouth County, N.J. (Marlboro, N.J., quadrangle)

This is a famous locality that has produced abundant invertebrate and vertebrate fossils for many years. In the nineteenth century this vicinity was actively mined for greensand marl, as the name of the adjacent township, Marlboro, attests. At this time a marl pit on the Rev. G. C. Schanck's farm, at a location quite close to this measured section, produced a number of dinosaur bones acquired by George Cook of Rutgers University and now in the collection of the AMNH. Today, the stream gravels are thoroughly worked by amateur paleontologists who continue to produce interesting vertebrate finds. The cliff exposures downstream contain typical Maastrichtian oyster shellbeds, while upstream from the bridge older beds produce Campanian invertebrates and vertebrates from underlying deposits. The first large acclivity on the south bank of the brook ¼ mile east of the bridge displays the following section (reading upward in section):

Description	Thickness	Total
Unctious massive micaceous silty clay grading upward into masive fine to medium well to moderately sorted clayey glauconitic sand, all olive gray (5 Y 3/2) in color; oyster-dominated shellbed at about 10 m above stream level.	12.5 m	12.5 m
Irregularly bedded indurated sand cemented by limonite, decreasing glauconite upward, dark yellowish orange (10 YR 6/6).	0.5	13.0
Clayey fine feldspathic quartz sand, light brown (5 YR 5/6), grading up into soil.	2.0	15.5

Weller's (1907) description of this locality makes it apparent that he considered the basal clay the Wenonah Formation, grading upward into typical Navesink greensand marl without any intervening Mount Laurel beds. Farther upstream, the dark clay deposits are undelain by laminated lignitic micaceous sands and dark gray clays with a siderite nodule layer that has produced a rich vertebrate scrap fauna. The fossils found in the point bar gravels, most commonly shark teeth, are thus probably derived from several sources. To further complicate matters, the streambed gravels and bank deposits have produced Pleistocene mammal remains (Parris, 1983; Gallagher et al., 1989). The difficulties of interpreting the various units below the Navesink along strike have been discussed by Gallagher et al.

(1986), and it is interesting to note that the problem is simlar to the situation regarding the interpretation of the units below the Hornerstown Formation, the next major transgressive glauconitic deposit upward in the section. Certainly the top of the Mount Laurel Formation changes from place to place, as noted by Gallagher (1984), and it may also be diachronous (Richards and Shapiro, 1963).

As noted above, George Cook obtained some dinosaur bones from a pit close by this section. Originally in the Rutgers University Geological Museum collection, they have been transferred to the AMNH, where they now reside. AMNH 3247-3250 consits of a hadrosaurian proximal end of radius, rib, large worn vertebral centrum, and a portion of the shaft of a leg bone. AMNH 2550-2553 is identified on the labels as *Coelosaurus antiquus*, but may be a juvenile *Dryptosaurus* (Denton and Gallagher, 1989). This material consists of the distal and proximal ends of the right tibia, three phalanxes (L III-1, R II-1, and R III-1), the distal end of right metatarsal II, and proximal end with shaft of right metatarsal IV. The labels given the horizon as "Greensand," so it is likely that the dinosaur specimens came from the Navesink Formation, the only glauconitic unit present at this locality. In addition to the dinosaurs, isolated bones of mosasaurs and plesiosaurs are found in the Navesink. Upstream, the dark gray clays of Marshalltown and Wenonah Formations produce a very varied scrappy fish fauna, along with turtle, crocodile, small theropod and mosasaur material (Gallagher et al., 1986; Lauginiger, 1986). Additionally, the Pleistocene sediments that occur along the stream banks contain reworked Cretaceous fossils along with the Pleistocene megafauna (Gallagher et al., 1989). These fossils can be recognized as reworked by their very battered and worn oxidized iron-stained appearance.

Section 10. Poricy Brook, Poricy Park, Lincroft-Middleton Road, Middleton, Monmouth County, N.J. (Long Branch, N.J., quadrangle)

At this well-known exposure, the township of Middleton has established a municipal park devoted to paleontology. Outcrops of the Navesink Formation along with the overlying Red Bank Formation are exposed in the brook's banks east of the Church Street bridge. The first large cliff in the south bank of the brook downstream from the bridge displays a section as follows (reading upward in section):

Description	Thickness	Total
Streambed.		0. m
Sandy glauconitic clay with glauconitic grains visible, medium dark gray (N4); prominent shellbed at 20-50 cm, mostly *Pycnodonte convexa*, massively bedded.	0.65 m	0.65
Clayey silty glauconite fine sand, shell fragments disseminated throughout, mica content increasing upward, olive gray (5 Y 3/2), massively bedded.	1.0	1.65
Micaceous clayey silty fine sand, abundant shell fragments and entire shells (Agerostrea sp.), olive gray (5 Y 3/2), massively bedded.	2.5	4.15
Clayey micaceous fine sand, light brown (5 YR 5/6) to dark yellowish orange (10 YR 6/6); contact with underlying unit abrupt and gently irregular; grading upward into modern soil zone.	2.0	6.15

Vertebrate fossils are generally rare here, although one of two finds of nodosaur from New Jersey came from the stream gravels in the brook; this is PU 21775, a tail vertebra. Occasional shark teeth of lamnoid type are also found here.

It is worth noting that the Navesink, especially in the basal shellbed here, is more clayey than at other sites nearby (for example, at Section 11, Atlantic Highlands, or Section 9, Big Brook). The overlying silty micaceous sand has been mapped as the Sandy Hook Member of the Red Bank Formation (Minard, 1969). The contact here, however, is gradational, marked mostly by an increase in mica upward; making this one unit seems just as logical.

Section 11. Bluffs along Raritan Bay, Atlantic Highlands, Monmouth County, N.J. (Sandy Hook, N.J., quadrangle)

East of the Atlantic Highlands marina along Raritan Bay, the Navesink and Red Bank Formations are exposed in high bluffs where the section strikes out to sea. Thus, this is the northeasternmost outcrop of the Maastrichtian deposits. A section taken at a brooklet falling down the bluff face approximately 0.75 km (ca ½ mile) east of the eastern gate of the marina reveals the following sequence (reading upward in section):

Description	Thickness	Total
Very micaceous glauconitic fine quartz sand, with siderite nodule at base (0 m), light olive gray (5 Y 5/2) to olive gray (5 Y 3/2), with some mottling; mica decreases upward.	0.5 m	0.5 m
Fine to medium glauconitic sand with small quartz pebbles in basal portion, greenish black (5 G 2/1 to 5 GY 2/1), with two distinct fossiliferous layers at 0.5-0.7 m and 0.8-0.9 m.	0.45	0.95
Clayey fine glauconitic sand with extensive mottling, massive, greenish black (5 GY 2/1 to 5 G 2/1), shell ghost beds from 1 m to 1.4 m and from 1.9 m to 2.2 m; occasional bone found on top.	1.25	2.2
Clayey fine glauconitic sand, massive, greenish black (5 GY 2/1 to 5 G 2/1), some mottling.	5.8	8.0
Concretionary layer, consisting of large flat glauconitic nodules, sometimes containing shell hash; matrix is greenish black (5 GY 2/1) with glauconite decreasing and mica increasing upward.	0.5	8.5
Lignitic micaceous fine sandy clay, grayish black (N2), lignite increasing upward; contact with overlying unit gradational.	1.0	9.5
Lignitic silty micaceous clayey fine sand, moderate brown (5 YR 3/4) to dark yellowish orange (10 YR 6/6); contact with overlying unit abrupt and irregular.	2.5	12.0
Lignitic micaceous silty fine sandy clay, grayish black (N2), contact with overlying unit sharp and flat, non-gradational.	2.25	14.25
Micaceous clayey fine quartz sand, dark yellowish orange (10 YR 6/6); top of section obscured by soil and slump.	1.25	15.5

The fossil concentration at the base of the Navesink Formation has been interpreted as a reworked bed (Minard, 1969). Actually, the fossiliferous horizon is separable into two layers, with a decimenter of unproductive glauconite between them. Cobban (1974) reported a diverse ammonite fauna from these layers, including foot-long complete *Baculites* specimens as well as specimens of delicately coiled heteromorph types such as *Nostoceras*. It would seem highly unlikely that such fragile fossils could survive any protracted period of reworking. Moreover, other molluscan fossils, for instance complete articulated bivalves and high-spired snails (which Rigby, 1988, has used as an argument against reworking) such as *Turritella*, suggest a different explanation. It is more likely that these concentrations have a more complex history involving slow sedimentation rates and biological interactions, as proposed by Kidwell (1989). There are also concentrations of shell ghosts that may represent the typical oyster beds of the Navesink, but diagenetic leaching by groundwater has reduced these shellbeds to curved mottles with the consistency of cream cheese.

Vertebrate remains tend to occur at the top of the first fossiliferous bed, and less frequently at the top of the second shell ghost layer. These include:

Chondrichthyes
- Lamnoid shark teeth
- cf. *Scapanorhyncus* sp.
- Elasmobranch vertebrae
- Batoid vertebrae
- ?*Brachyrhizodus* sp. (teeth)
- *Edaphodon triparitus*
- *Ischyodus bifurcatus*
- Shark coprolites
- *Ischyrhiza mira* rostral spines

Osteichthyes
- *Anomoeodus phaseolus* teeth
- *Enchodus ferox* teeth
- cf. *Xiphactinus* ? scales
- Teleost vertebrae

Reptilia
- *Corsochelys* sp.
- *Osteopygus* sp.
- *Peritresius ornatus*
- *Mosasaurus maximus*
- *M. conodon*
- *Cimoliasaurus magnus*
- cf. *Titanopteryx* sp.
- Portion of hadrosaur mandible

Section 12. Beers Hill, Holmdel Road, 0.5 Mile North of Crawford Corner, Monmouth County, N.J. (Keyport, N.J., quadrangle)

On the east of Holmdel Road between Longview Drive and Georgean Drive just west of the AT&T Bell Telstar Laboratories, a roadcut through Beers Hill exposes the Tinton Formation. This indurated unit is restricted to northeastern Monmouth County in its areal extent, and does not persist far into the shallow subsurface (Olson, 1963, 1975). The following sequence is seen here (reading upward in section):

Description	Thickness	Total
Bottom of section obscured by slump and vegetation.	1.5 m	1.5 m
Micaceous clayey fine to medium quartz sand, light brown (5 YR 5/6) to moderate reddish brown (10 YR 4/6).	1.5	3.0
Glauconitic quartz sandstone streaked with limonitic staining, weathering to loose sand with iron-cemented crust, prominent indurated ledge in basal 0.75 m; olive gray (5 Y 3/2) to dark yellowish orange (10 YR 6/6), massive.	3.0	6.0
Glauconitic sandstone with fossil shell impressions and steinkerns, some vivianite; moderate olive brown (5 Y 4/4) to grayish blue (5 PB 5/2).	0.5	6.5
Glauconitic quartz sandstone with abundant fossils, dusky yellow (5 Y 6/4) to blackish red.	0.75	7.25
Indurated nodular layer of ironstone concentric concretions, dark yellowish orange (10 YR 6/6) to grayish red purple (5 RP 4/2).	1.25	8.5
Clayey glauconitic fine to medium quartz sand, light olive gray (5 Y 5/2), mottled	0.5	9.0
Ironstone concentric concretions, dark yellowish orange (10 YR 6/6) to grayish red purple (5 RP 4/2).	0.5	9.5
Clayey fine to medium glauconitic sand with some quartz grains, grayish olive green (5 GY 3/2).	0.5	10.0
Concretionary ironstone, dark yellowish orange (10 YR 6/6), grading upward into soil horizon.	0.5	10.5
Soil.	0.5	11.0

The reddish brown sand at the base is the Red Bank Formation, while the greensand at the top of the section is the Hornerstown Formation. In between, the indurated glauconitic sands contain a late Maastrichtian marine invertebrate fauna that is mostly concentrated in two distinct beds near the top of the Tinton Formation. The mollusks' internal molds are largely divided between *Tachycardium*, *Exogyra costata*, and *Trigonia*, but the most common fossils here are the numerous claws of *Protocallianassa mortoni*, a burrowing malacostracan crustacean. The shells are generally single valves and often broken, and there is no development of a well-defined oyster bed; *Exogyra* is less common here than in the glauconitic units lower down in the section. The sands are coarser and more quartzose than the glauconitic formations above and below, suggesting a higher-energy depositional environment with a higher input of clastics. Moreover, the callianassids today dig extensive burrows in near-shore sands, making it likely that the Tinton Formation represents a different environment from the other glauconitic beds.

Section 13. Tinton Falls, at the intersection of Sycamore and Tinton Sts., Tinton Falls, Monmouth County, N.J. (Long Branch, N.J., quadrangle)

This is the type area of the Tinton Formation, and the best exposure today is at the falls formed by Swimming Brook as it passes over the glauconitic sandstone. A section in the north bank just downstream of the falls ledge reveals the following sequence (reading upward in section):

Description	Thickness	Total
Medium to coarse glauconitic sandstone, dusky yellowish green (10 GY 3/2), with a few shell fragments; massive.	0. m	0.5 m

Coarse poorly sorted glauconitic quartz sandstone with quartz granules and small quartz pebbles, dark reddish brown (10 R 3/4) to olive gray (5 Y 3/2) with streaks of dark yellowish orange (10 YR 6/6) iron oxide; shell fragments, entire valves, and arthropod claws disseminated throughout.	1.5	2.0
Sandstone weathering into modern rooted soil.	0.5	2.5

In this outcrop, the Tinton is more glauconitic at the base of the section and coarser and more quartzose upward. In addition to the mollusk steinkerns and *Protocallianassa mortoni* claws, the ammonite *Sphenodiscus lobatus* has been found at this locality. Since this form has only been reported from the Tinton Formation in northeastern New Jersey (Weller, 1907; Richards et al., 1962), it can be regarded as a zone fossil for the uppermost Maastrichtian in this area.

In the AMNH collections there are several interesting vertebrate specimens recorded from Tinton Falls, including the type of *Taphrosphys sulcatus* (AMNH 2522), the type of *Adocus pravus* (AMNH 2528), a specimen of *Hyposaurus rogersii* (AMNH 2545), and a specimen of *Thoracosaurus neocesariensis* (AMNH 2548). This fauna has a distinctively Hornerstown cast to it, and it is more likely from that unit rather than from the Tinton Formation. While the Hornerstown Formation is not to be seen at this section, it is likely that it is present in the vicinity and was perhaps mined for greensand marl. If so, these vertebrate remains may represent a northeastern-most extension of the basal Main Fossiliferous Layer that has produced so many specimens from pits elsewhere further to the southwest.

Section 14. Good Intent, Blackwood Terrace, Gloucester County, N.J. (Runnemede, N.J., quadrangle)

Historically this vicinity has produced important specimens from the K/T section, as for example the type specimen of the crocodilian *Hyposaurus rogersii*, named for its collector, Henry Darwin Rodgers. The Navesink-Hornerstown contact was extensively exposed in the cuesta across from Big Timber Creek at Church Street, in an area known as Good Intent. Although this locality has been graded, fossils are still abundant here and the various layers are easy to locate. Gallagher (1984) described briefly the measured section; a more detailed description is presented here (reading upward in section).

Description	Thickness	Total
Medium to coarse subangular clayey poorly sorted glauconitic sand with quartz granules; burrow mottling, massive; grayish olive (10 Y 4/2) to light brown (5 YR 6/4); shellbed at base with abundant oysters and other molluscan steinkerns; some vertebrate material.	0.3 m	0.3 m
Medium to very coarse clayey silty iron-cemented glauconitic quartz sand, very poorly sorted, subangular to subrounded, ironstone layers stratified; light brown (5 YR 6/4) to dark yellowish organe (10 YR 6/6); shell fragments at top.	0.4	0.7
Medium to coarse clayey glauconitic sand with quartz granules, mica, and gypsum crystals; subrounded to subangular, moderately to poorly sorted; mottled, burrowed, massive; moderate brown (5 YR 3/4) to olive gray (5 Y 3/2); molluscan steinkerns disseminated throughout.	4.3	5.0
Indurated iron-oxide cemented fine to coarse clayey glauconitic quartz sandstone with limonite; subrounded to subangular, moderately to poorly sorted; thoroughly burrowed, burrows filled with greenish black (5 G 2/1) glauconite; massive; dusky yellowish brown (10 Y 2/2) to moderate yellowish brown (10 YR 5/4) with grayish green (10 GY 5/2) and light brown (5 YR 5/6).	0.8	5.8
Greensand with quartz, fine to medium; subrounded to subangular; well to moderately sorted; massive, extensively burrowed; grayish olive green (5 GY 3/2) weathering to dusky yellow green (5 GY 5/2); fossiliferous layer from 6.0 to 6.1 m contains abundant invertebrate and vertebrate fossils; increasingly limonitic and moderate brown (5 YR 3/4) at top.	3.3	9.1
Clayey sandy gravel, slumped and disturbed in places.	3.9	13.0

The shellbed at the base of the section contains a typical Cretaceous oyster bank assemblage dominated by steinkerns of *Exogyra costata*, *Pycnodonte convexa*, and *Agerostrea mesenterica*; typical Navesink subsidiary taxa found here include phragmocones of *Belemnitella americana*, the ammonite *Baculites ovatus*, and the small brachiopod *Choristothyres plicata*. There are numerous other molluscan fossils at this level, especially grazing (*Anchura pennata*) and carnivorous (*Gyrodes abyssinus*, *Lunatia halli*, *Pyropsis trochiformis*) gastropods. The shellbed has also produced

numerous mosasaur specimens including isolated teeth, vertebrae, and skull elements (NJSM 13421) (Gallagher, 1984).

At the fossiliferous level between 6.0 and 6.1 meters, two decimeters above the Navesink-Hornerstown contact, the abundant invertebrate fossils are *Pycnodonte dissimilaris*, *Cucullaea vulgaris* and *Turritella mortoni.* The oyster shells are generally at or just below the 6.0 m level; the majority of the vertebrates, including lamnoid sharks' teeth, a lower jaw of *Thoracosaurus* cf. *neocesariensis* and a portion of the carapace of *Taphrosphys* sp. (both ANSP) were found closely associated with the infaunal suspension-feeding benthos above the oyster layer.

Finally, at the top of the Hornerstown Formation, from above 2 to 3 meters above the basal contact with the Navesink, there is a third assemblage dominated by the sponge *Peronidella dichotoma* and the coral *Flabellum mortoni.* Associated with these epifaunal benthos are teeth and vertebrae of lamnoid sharks. Above this is the erosionally resistant Pensauken Formation, a Pleistocene outwash gravel that caps the cuesta.

Section 15. West bank of Crosswicks Creek, 1/4 mile north of Rt. 537 Bridge (New Egypt, N.J., quadrangle)

In recent years an interesting fossil assemblage has been collected from the basal Hornerstown Formation in the banks of the creek at this spot. The following sequence is exposed (reading upward in section):

Description	Thickness	Total
Micaceous, quartzose, clayey glauconitic fine sand, moderately to well sorted; brownish black (5 YR 2/1); massive, extensively mottled by glauconite-filled burrows; bivalve shells throughout, also filled with glauconite.	0.95 m	0.95m
Clayey glauconitic fine to medium sand, well to moderately sorted; brownish gray (5 Y 4/1), greenish black (5 GY 2/1); thoroughly burrowed; abundant invertebrate fossils.	0.15	1.1
Fine to medium glauconite sand, moderately to well sorted; greenish-black (5 GY 2/1) mottled with brownish gray (5 Y 4/1); abundant vertebrate and invertebrate remains in basal 30 cm; some iron oxide streaking.	1.0	2.1
Glauconite sand grading upward into rooted modern soil.	1.0	3.1

The fossil concentration around the base of the Hornerstown Formation displays an internal microstratigraphy and complexity characteristic of the condensed beds described by Kidwell (1989). A lower thoroughly bioturbated zone is topped by a zone with abundant vertebrate remains. This vertebrate fauna is correlative to the vertebrate assemblages found in the basal Hornerstown all along strike. Generally the vertebrates lay on top of a layer rich with invertebrates dominated by *Cucullaea vulgaris*, *Turritella mortoni*, and the oyster *Pycnodonte dissimilaris.* The following specimens in the NJSM collection are from this site:

Bivalvia
- *Pycnodonte dissimilaris*
- *Cucullaea vulgaris*

Gastropoda
- *Turritella mortoni*

Chondrichthyes
- Shark teeth, cf. *Odontaspis*

Osteichthyes
- *Enchodus* sp.

Reptilia
- *Thoracosaurus neocesariensis*
- *Agomphus* sp.
- *Osteopygis emarginatus*
- cf. *Taphrosphys* sp.

Section 16. Inversand Pit, Sewell, Mantua Township, Gloucester County, N.J. (Woodbury, N.J., quadrangle)

The Inversand Pit is the sole surviving representative of a once thriving industry in southern New Jersey, the mining of greensand marl. Dug in the nineteenth century for agricultural purposes, today this unusually pure deposit of glauconite is mined for use as an industrial water-softener because of its high ion-exchange capacity. Because it is the last of its kind, it offers us a sampling of what nineteenth-century paleontologists had at their disposal all along the inner coastal plain, from Monmouth County down to Gloucester County. For this reason the stratigraphy is worth noting in detail, as follows (reading upward in section):

Description	Thickness	Total
Shellbed, primarily of oysters (density of 7 valves/dm^3 average) in clayey, medium to coarse glauconite sand, olive gray (5 Y 3/2).	0.2 m	0.2 m
Clayey medium to coarse glauconitic sand with occasional small quartz pebbles and nodules of vivianite, shell density decreasing upward, olive gray (5 Y 3/2) with burrows filled in by glauconite sand, dusky yellowish green (10 GY 3/2); grades upward into next unit.	1.0	1.2
Sandy glauconitic clay, with occasional small quartz pebbles, scattered molluscan steinkerns and clusters of small gregarious oysters (*Agerostrea*), dusky brown (5 YR 2/2) to dusky yellowish brown (10 YR 2/2) with extensive burrows filled in by glauconite sand, dusky yellowish green (10 GY 3/2) in color.	2.0	3.2
Clayey fine to medium glauconite sand (greensand), grayish olive green (5 GY 3/2) mottled with burrows, dusky brown (5 YR 2/2).	0.15	3.35
Main Fossiliferous Layer (MFL); complex shellbed consisting of dense oyster (*Pycnodonte dissimilaris*) bed at base, concentrations of *Cucullaea vulgaris* and other molluscan steinkerns plus vertebrate remains, with isolated vertebrate remains (reptile bones, sharks teeth) found at top; in matrix of clayey fine to medium glauconite sand, grayish olive green (5 GY 3/2).	0.3	3.65
Clayey, medium to fine glauconite sand (greensand), moderately to well sorted; scattered burrows, massive; small clusters of radiating acicular gypsum crystals becoming more common toward top of unit; between 2 and 3 m above contact with underlying formation, a disseminated fossil assemblage dominated by *Peridonella dichotoma*, *Flabellum mortoni* and *Terebratulina atlantica* occurs; grayish olive green (5 GY 3/2) to dusky yellowish green (10 GY 3/2).	5.0	8.65
Iron oxide-stained glauconitic indurated quartz sand.	0.05	8.7
Micaceous glauconitic very fine to medium quartz sand, more clayey and glauconitic at base; glauconite decreasing and quartz increasing upward; coarse quartz granules and small pebbles scattered through top; grayish olive green (5 GY 3/2) with moderate yellow (5 Y 7/6) mottling at base to grayish orange (10 YR 7/4) upward; no visible megafossils; contact with overlying unit abrupt.	3.5	12.2
Silty, clayey very fine quartz sand, dark yellowish orange (10 YR 6/6) to very pale orange (10 YR 8/2); no visible megafossils.	1.5	13.7
Clayey gravel with large quartz and chert pebbles; pebbles concentrated in densely-packed gravel at contact with underlying formation; chert pebbles contain Paleozoic marine fossils (rugose and tabulate corals, brachiopods, crinoids); dark yellowish orange (10 YR 6/6).	2.0	15.7

This operation has historically produced important vertebrate remains (see, for example, Chaffee, 1939; Colbert, 1948; Baird, 1964) and has been the subject of continuous monitoring and study by NJSM staff (Gallagher and Parris, 1985; Gallagher et al., 1986; Olson and Parris, 1987; Parris, 1986). This series of intensive investigations has clarified the stratigraphic relationships in this critical portion of the K/T sequence. Many of the important dinosaur finds in this pit come from just above the shellbed in the Navesink Formation, approximately 2 to 3 meters below the Navesink-Hornerstown contact; however, I have recently recovered a hadrosaur vertebra (NJSM) only one decimeter below this formational contact, and numerous isolated mosasaur bones and teeth have been found just above it in the MFL. The complex internal stratigraphy, plus its setting in a condensed section, make the MFL a candidate for status as an example of Kidwell's (1989) basal condensed shellbeds. In the upper part of the Hornerstown, only a crocodile, some fragmentary turtle shell, and sharks' teeth are found (Parris, 1986), in addition to the depauperate and dwarfed invertebrate fauna. These changes in the fossil assemblages represent a real faunal changeover, the K/T mass extinction event. For further detailed discussion of this site, see parts 3 and 4 of the present paper.

Section 17. Tributary of Big Timber Creek, west of intersection of Warwick and Laurel Roads, Stratford, Camden County, N.J. (Runnemede, N.J., quadrangle)

A culvert under an intersection has channeled floodwaters into eroding a deep gulley, creating a small waterfall over a resistant ledge marking the contact between two stratigraphic units. This section was measured at the steep bank by the waterfall (reading upward in section).

Description	Thickness	Total
Clayey fine to medium glauconite sand, or greensand, greenish black (5 G 2/1); downstream, abundant specimens of *Peridonella dichotoma* at stream level *in situ*; between 0.4 and 0.6 m, layer containing *Oleneothyris harlani* and pelecypods.	1.0 m	1.0 m
Indurated iron-oxide stained glauconitic sand, greenish black (5 G 2/1) to dark yellowish orange (10 YR 6/6).	0.5	1.5
Fine glauconitic quartz sand, dusky yellow (5 Y 6/4).	1.5	3.0
Medium to coarse quartz sand with gravel, dark yellowish orange (10 YR 6/6) to moderate red (5 R 4/6).	1.0	4.0

This exposure demonstrates the continuity of the *Oleneothyris harlani* biozone along strike; moreover, the sponge *Peridonella dichotoma*, characteristic of the upper Hornerstown Formation, is also found here in large numbers at the base of the section. The boundary between the Hornerstown and Vincentown Formations is marked by the indurated iron oxide-stained layer, probably formed by diagenetic precipitation of iron oxide at a major change in sediment permeability. This is a common geochemical phenomenon at formational boundaries in Coastal Plain sediments, although it is not necessarily present at all contacts.

The upper part of the Hornerstown Formation here marks the first occurrence of the large lamnoid *Otodus appendiculata*, first of the big Tertiary sharks. Two- to three-inch teeth are occasionally found in the point bars below the waterfall (Gallagher, 1984). *Otodus* is the most obvious of the new elasmobranchs to appear in the Coastal Plain K/T section after the mass extinction event.

Section 18. Shingle Run, east-flowing tributary of Crosswicks Creek, and adjacent bluffs on Crosswicks Creek, New Egypt, Ocean County, N.J. (New Egypt, N.J., quadrangle)

A remarkable concentration of the brachiopod *Oleneothyris harlani* is exposed in the banks of Shingle Run and along the Crosswicks Creek's west bank just north of Shingle Run. A section starting at base level of the stream bed was measured:

Description	Thickness	Total
Shell-supported brachiopod gravel in greensand matrix; greensand is fine to medium, well to moderately sorted, dusky yellowish green (10 GY 4/4).	0.3 m	0.3 m
Greensand, fine to medium, well to moderately sorted, brachiopod shell density thinning out, grayish green (5 G 5/2) to dusky yellowish green (10 GY 4/4).	0.1	0.4
Greensand, fine to medium, well to moderately sorted, occasional brachiopod shell, grayish green (5 G 5/2) to dusky yellowish green (10 GY 4/4).	0.25	0.65
Clayey glauconitic quartz sand, very fine to coarse; poorly sorted, massive; light olive gray (5 Y 5/2) to olive gray (5 Y 3/2); shellbed of broken brachiopod valves at base, shells in several layers upward.	0.65	1.3
Indurated shellbed with glauconitic quartz sandstone cemented by iron oxide, dark yellowish orange (10 YR 6/6) to very pale orange (10 YR 8/2); forms prominent ledge.	0.1	1.4
Glauconite quartz sand, fine to medium, massive, grading upward to calcareous quartz sand with glauconite and lithic grains, fine to coarse, massive, with several thin indurated layers, grayish yellow (5 Y 8/4); bryozoa fragments increasing in abundance upward.	4.0	5.4

As usual in the New Jersey Coastal Plain, there has been disagreement as to where to place the *Oleneothyris* biostrome stratigraphically. Weller (1907) was ambiguous on this point, pointing out that the brachiopod bed could be considered either the top of the Hornerstown or the base of the Vincentown Formation. Olsson (1975) and Feldman (1977) considered the shellbed to be the top of the Hornerstown, while USGS workers (Owens and Sohl, 1969) regard it as the bottom of the Vincentown. The truth is that it is both, as Weller suspected. In the section presented here, it is clear that there is a distinct lithologic break at 0.65 m, marked by a concentration of broken brachiopod valves; below this point the sediment is dominantly glauconitic, while above there are still abundant *Oleneothyris* shells but in a less glauconitic matrix. So I would place the Hornerstown-Vincentown contact at this lithostratigraphic boundary, while the biostratigraphic range of *O. harlani* bridges the formational contact.

Feldman (1977) has demonstrated a morphologic change in the *Oleneothyris* population at this locality. He has also noted the overwhelming domnance of *O. harlani* in the fuana, which he quantifies as composing 99% of the megafossil assemblage. For various reasons, Feldman considers this bed a non-reworked biocoenosis. Statistically-treated samples of *O. harlani* from this section show an upward trend from shorter, flatter shells with small pedicle openings to longer, more inflated cylindrical shells with larger pedicle openings. He attributes this change, as well as the low diversity of the assemblage, to evolutionary adaptation of the population in response to regression, increased wave and current action, and turbulence as the deeper waters of Hornerstown time shoaled into Vincentown depths. A more robust shell with a larger more muscular pedicle would have proven more advantageous under these conditions, according to Feldman (1977).

There are other possible explanations, of course, including sexual dimorphism or standard age and/or ecomorphic variation within the brachiopod population (Gallagher, 1984). The shellbed shows some attributes of complex condensed-section shellbeds (Kidwell, 1989) because while many of the brachiopod specimens are articulated bivalved individuals, there is also a mixture of single and broken valves (Gallagher, 1984). Feldman (1977) has noted the presence of crowding deformation on some shells, and an alternative view of this assemblage is as a shell gravel community; in this interpretation, ecomorphic change is driven by the increasing hardness of the substrate, a process Kidwell and Jablonski (1983) have called taphonomic feedback. Thayer (1979, 1983) has demonstrated that brachiopods were forced off of soft substrates by infaunal bioturbators, especially during a radiation of infauna in the Cretaceous. It is curious, then, to find this abundant a concentration of brachiopods in the Paleocene, in a soft glauconitic matrix. The answer to this apparent paradox is that the brachiopods were opportunists who occupied the niche of shell gravel colonizers previously dominated by Cretaceous oysters. Indeed, there are a few rare oyster shells mixed in with the overwhelmingly dominant *Oleneothyris* shells, as if to confirm this concept.

Given this assumption, one could conclude that the morphologic change observed by Feldman represents a response to changing substrate conditions, with an initial "snow-shoe" design (Thayer, 1975) giving way to a shell shape more adapted to a hard shell-gravel bottom. Thayer (1986) has suggested that brachiopods might be better suited to post-K/T boundary conditions than pelecypod competitors, primarily in terms of harvesting food resources, and this shellbed seems to bear his ideas out. An additional advantage would be conferred on non-planktotrophs such as brachiopods, as discussed in part 3 of the present paper.

Section 19. Alloway's Pit, east of Newbold Corner Road, Vincentown, Southampton Township, Burlington County, N.J. (Mount Holly, N.J., quadrangle)

Excavations for an irrigation pond revealed a complete section of the Vincentown Formation less than a kilometer away from the best exposure of the Vincentown limesand facies on the banks of Rancocas Creek (see Section 20). The section, described below, is interesting for what it reveals about rapid lateral facies changes in the Vincentown Formation. Reading upward in section:

Description	Thickness	Total
Fine to medium clayey greensand, dusky yellowish green (10 GY 4/4), with abundant articulated specimens of *Oleneothyris harlani*.	0 - 0.5 m	0.5 m
Fine to medium glauconitic quartz sand, light olive gray (5 Y 3/2) indurated at top.	1.0	1.5
Fine to medium quarz sand, pale yellowish orange (10 YR 8/6) darkening upward to dark yellowish orange (10 YR 6/6); fossil fragments, especially pieces of the bryozoan *Coscinopleura digitata* and echinoid spines, increasing in abundance upward.	1.3	2.8
Clayey gravel, predominantly quartz pebbles; dark yellowish orange (10 YR 6/6).	0.1	2.9
Fine sandy silty glauconitic clay, light olive (10 Y 5/4) lightening upward to pale olive (10 Y 6/2).	0.7	3.6

The changeover from glauconite sand to quartz sand at the base of the section here is gradational, and it is difficult to establish a lower formational contact if one exists. On the other hand, the abrupt lithologic change at the 2.9 m level is marked by a conspicuous pebble layer, and this would appear to be the contact between the Vincentown Formation and the overlying Manasquan Formation of Early Eocene age.

While there are no fossils apparent in the Manasquan Formation, the Vincentown here contains abundant specimens. At the base level of the pond articulated shells of the brachiopod *Oleneothyris harlani* abound, with a minor faunal component of *Pycnodonte dissimilaris* and *Polorthus tibialis*. Above the indurated layer, the quartz sand contains disseminated fragments of the cheilostome *Coscinopleura digitata* that increase in number upsection until the pebble layer. A faunal list from the Vincentown here includes:

Coelenterata
- *Graphularia ambigua* (Morton)

Brachiopoda
- *Oleneothyris harlani*

Pelecypoda
- *Pycnodonte dissimilaris*
- *Gryphaeostrea vomer*
- *Ostrea panda* Morton
- *Arca quindecemradiata* Gabb
- *Cucullaea* sp.
- *Crassatellites* sp.?
- *Caryatis veta* Whitfield
- *Periplomya* sp.
- *Pinna rostriformis* Morton
- *Leda* sp.
- cf. *Tenea* sp.
- *Polorthus tibialis* Whitfield
- *Gastrochaena americana* (Gabb)

Gastropoda
- *Turritella mortoni*
- *Pleurotrema solariformis* Whitfield
- cf. *Rostellites biconicus* Whitfield
- ?*Volutomorpha* sp.
- *Pyropsis* sp.
- *Piestochilus* sp.
- *Anchura* sp.

Bryozoa
- *Coscinopleura digitata*
- various encrusting forms

Echinodermata
- Echinoid spines
- *Salenia tumidula* Clark

Chordata: Chondrichthyes
- *Striatolamna* cf. *striata* (Winkler) teeth
- *Palaeohypotodus* sp. teeth
- *Otodus* sp. teeth
- *Cretolamna appendiculata* teeth
- *Rhinoptera* vertebra
- *Rhombodus* sp. dermal denticle
- *Myliobatis jugosus* Leidy teeth
- *Edaphodon* sp. jaw elements

Chordata: Osteichthyes
- Teleost pectoral spines, hypural fans, and vertebrae

The limesand facies is missing here, although the quartz sand has a significant carbonate component from the abundant bryozoan fragments. An interesting pheonomenon is the dominance of lamnoid shark teeth among the Chondrichthyans; among Cretaceous chondrichthyans, *Squalicorax* and *Scapanorhynchus* are the dominant shark tooth genera.

Section 20. South Branch of Rancocas Creek, Vincentown, Southampton Township, Burlington County, N.J. (Mount Holly, N.J., quadrangle)

This is the type locality for the Vincentown Formation, and in a series of steep bank outcrops north of the Stokes Cannery and west of Newbolds Corner Road, the Rancocas Creek has eroded an exposure of the limesand facies of this unit (reading upward in section):

Description	Thickness	Total
Limestone (bryozoan calcarenite), with common ahermatypic corals (*Flabellum mortoni*) and mollusk shells, yellowish gray (5 Y 7/2).	0.5 m	0.5 m
Clayey fine to medium bryozoan limesand with glauconite and quartz grains, yellowish gray (5 Y 7/2).	1.0	1.5
Limestone, yellowish gray (5 Y 7/2) stained with moderate reddish brown (10 R 4/6) iron oxide, irregular top and bottom surfaces.	0.2	1.7
Clayey fine to medium bryozoan limesand, medium to well sorted, with quartz and glauconite grains, yellowish gray (5 Y 7/2).	1.0	2.7

Limestone layer, yellowish gray (5 Y 7/2), irregular top surface.	0.2	2.9
Limesand, yellowish gray (5 Y 7/2).	0.1	3.0
Limestone layer, yellowish gray (5 Y 7/2).	0.2	3.2

(Top of section obscured by soil slump and overgrowth.)

This is a unique deposit in the Atlantic Coastal Plain Cretaceous-Tertiary sequence; nowhere else in the K/T outcrop belt is limestone encountered. The indurated carbonate apparently caused erosional resistance, for the Rancocas takes a bend around these beds leaving them standing in a steep bluff in what is otherwise a very low gradient lowland area. In fact, just a short distance along strike to the northeast at Alloway's Pit (see Section 19) the limesand facies is not observed, and it is not to be seen in other exposures of the Vincentown (for example, at Section 16, the Inversand Pit). This carbonate depositional environment, then, is only represented in localized patches or lenses. To be sure, both the quartz sand and glauconite facies of the Vincentown have in some spots a greater or lesser bryozoan content, but it is in the limesand facies that the concentration of bryozoan fragments (especially *Coscinopleura digitata*) reaches its greatest abundance. Moreover, the limited nature of the deposit is apparent in the maps provided by Bader and Wolfe (1948) in their report on the economic potential of the limesand beds at Vincentown, and Graecen (1941) noted the lenticular nature of the limesand facies in her comprehensive study of the Vincentown Formation.

In light of these observations, it is worth looking at the fauna more closely. The overwhelmingly dominant component of the fauna is the Bryozoa; Canu and Bassler (1933) listed 85 species in the Vincentown, most of which are found at the type locality. Of these, 67 species are non-planktotrophic cheilostomes, and of these the dominant species is *Coscinopleura digitata*, which can compose over 80% of the megafossil clasts in any given sample of the limesand (R. Ramsdell, personal communication).

Another remarkable feature of this fauna is the exceptional preservation of echinoids in the limesand. At the type section, there are commonly found complete regular and irregular echinoids with their thin tests showing little or no damage. They are usually preserved in the hard limestone layers. Elsewhere in the Vincentown Formation, the fragments of tests or isolated spines may be common, but entire tests are very rare in the quartz or glauconite sand facies. Cooke (1959) listed ten species of echinoids from the Vincentown Formation, all from limesand facies outcrops.

Other faunal elements (gorgonians, crinoids, serpulid worms) complete the picture. Gallagher (1984) has proposed that the limesand facies represents a bryozoan patch reef environment. In this view, the lenticular nature and faunal content of the limesand are explained as the result of organic carbonate build-ups; in place of scleractinian framework builders (which were decimated by the K/T extinction; Kaufman, 1984), the encrusting and branching bryozoans became the major carbonate contributors. They were additionally favored by being non-planktotrophs. The Vincentown limesand facies thus represents the first resurgence of the reef community's diversity after the K/T extinction. It should be noted in this regard that the closest faunal affinities of Vincentown limesand bryozoans are to the type Danian bryozoans (Canu and Bassler, 1933), and that Bromley (1979) characterized the type Danian bryozoan mounds as biohermal.

(Diagrammatic illustrations of Sections 1-20 follow)

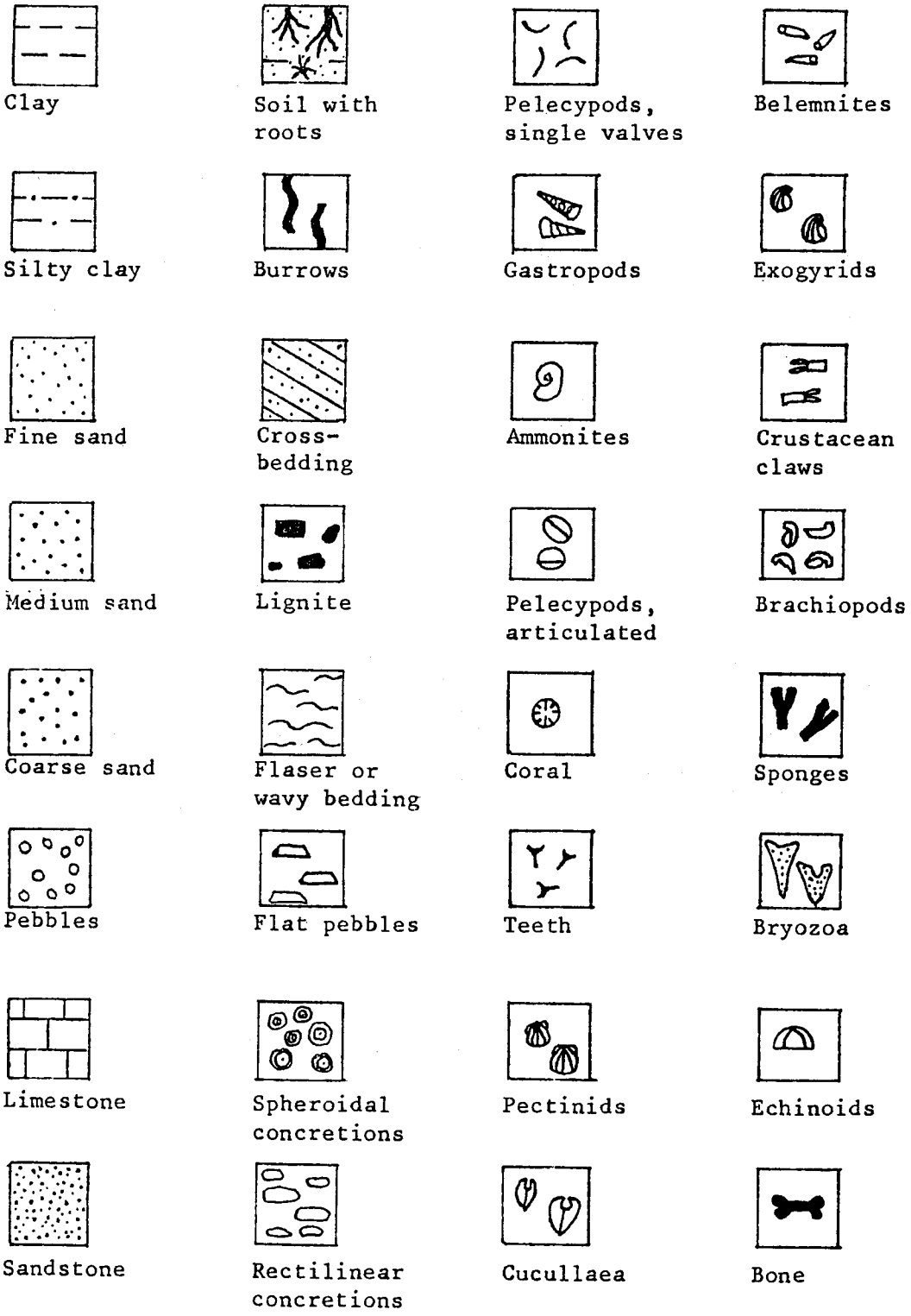
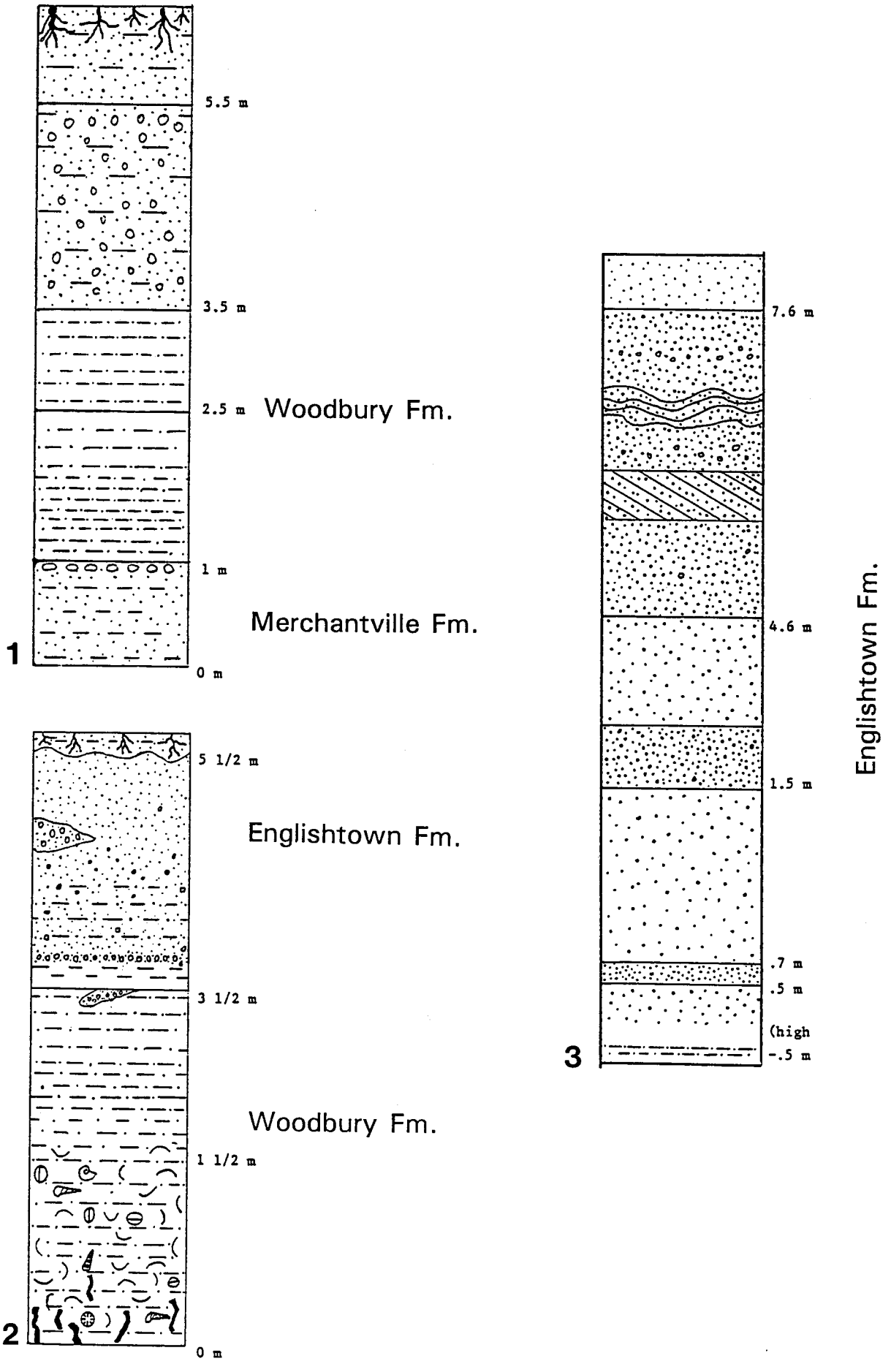
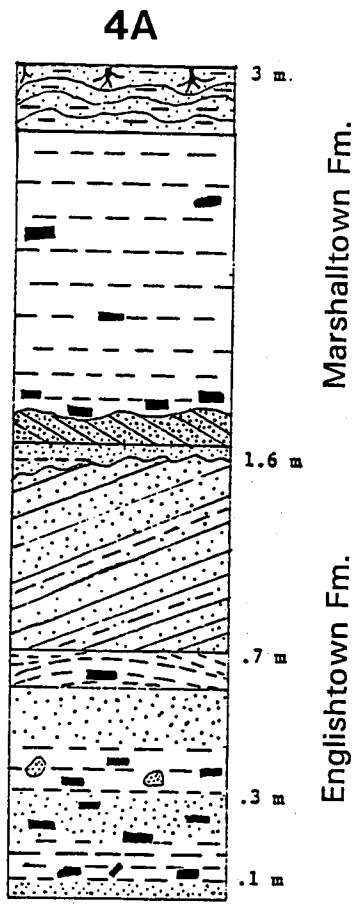
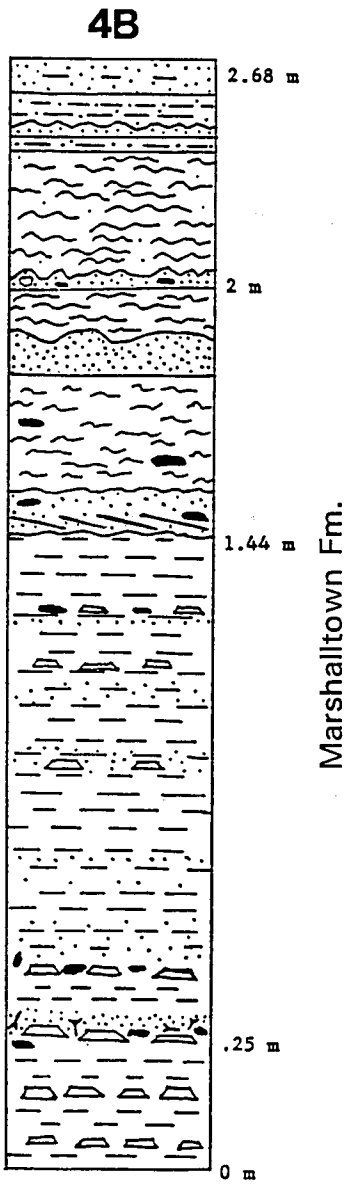
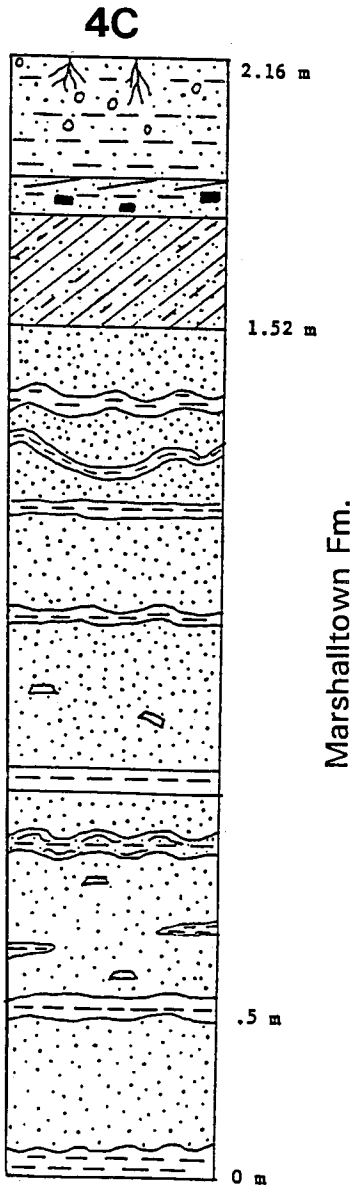


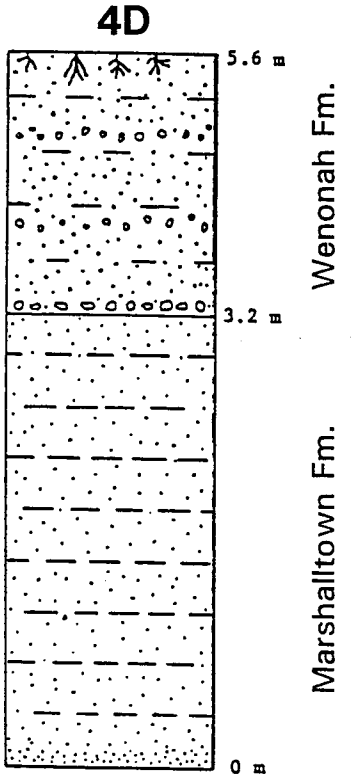
Figure A-1. Lithologic and paleontologic symbols used in measured sections 1-20 (following pages).

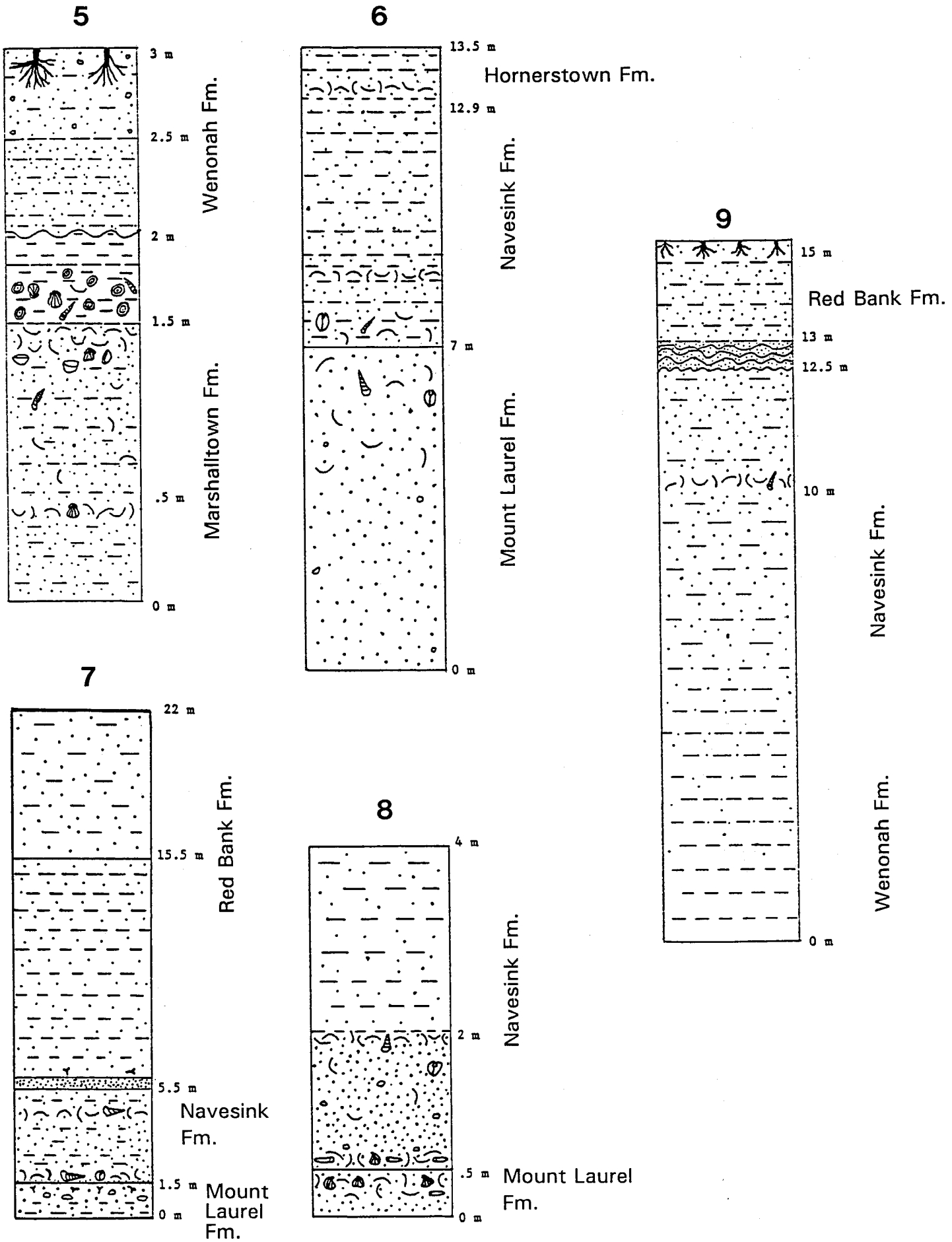

5.5 m
3.5 m
2.5 m
Woodbury Fm.
1 m
Merchantville Fm.
1
0 m
5 1/2 m
Englishtown Fm.
3 1/2 m
Woodbury Fm.
1 1/2 m
2
0 m
7.6 m
4.6 m
1.5 m
.7 m
.5 m
(high
-.5 m
3
Englishtown Fm.

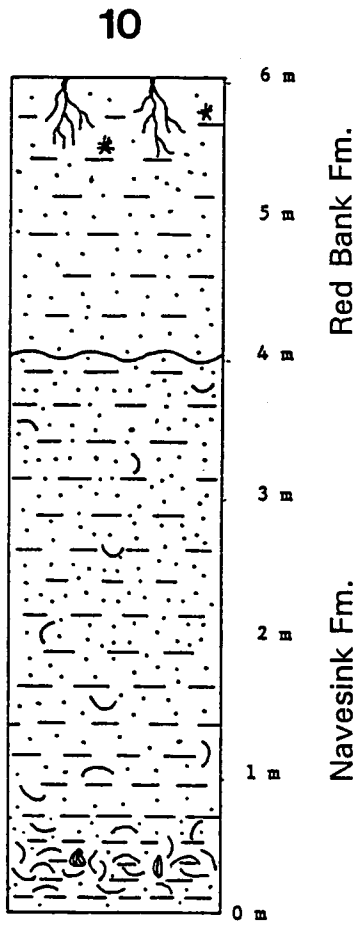

4A
3 m.
1.6 m
.7 m
.3 m
.1 m
Marshalltown Fm.
Englishtown Fm.

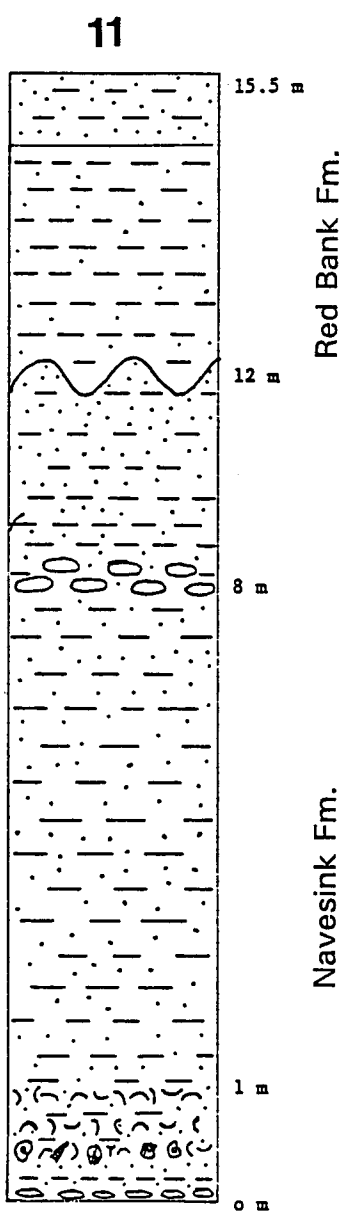

4B
2.68 m
2 m
1.44 m
.25 m
0 m
Marshalltown Fm.

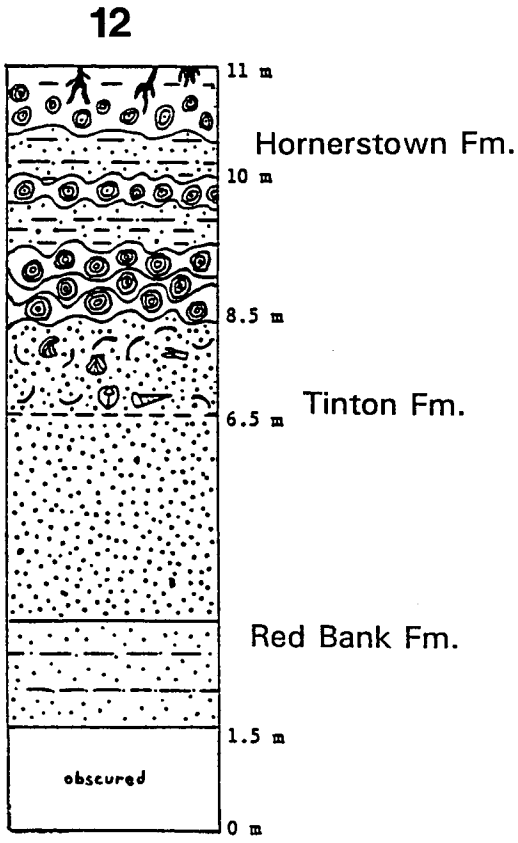

4C
2.16 m
1.52 m
.5 m
0 m
Marshalltown Fm.

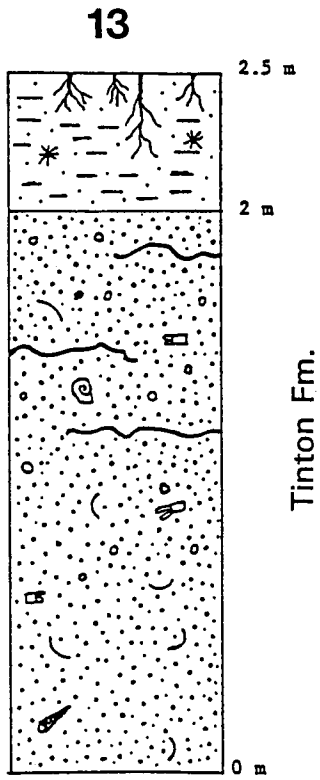

4D
5.6 m
3.2 m
0 m
Wenonah Fm.
Marshalltown Fm.

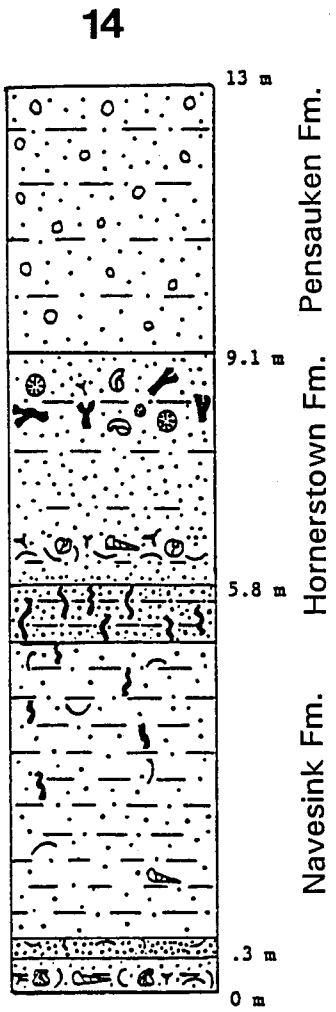

5
3 m
2.5 m
2 m
1.5 m
.5 m
0 m
Wenonah Fm.
Marshalltown Fm.
6
13.5 m
12.9 m
7 m
0 m
Hornerstown Fm.
Navesink Fm.
Mount Laurel Fm.
9
15 m
13 m
12.5 m
10 m
0 m
Red Bank Fm.
Navesink Fm.
Wenonah Fm.
7
22 m
15.5 m
5.5 m
1.5 m
0 m
Red Bank Fm.
Navesink Fm.
Mount Laurel Fm.
8
4 m
2 m
.5 m
0 m
Navesink Fm.
Mount Laurel Fm.

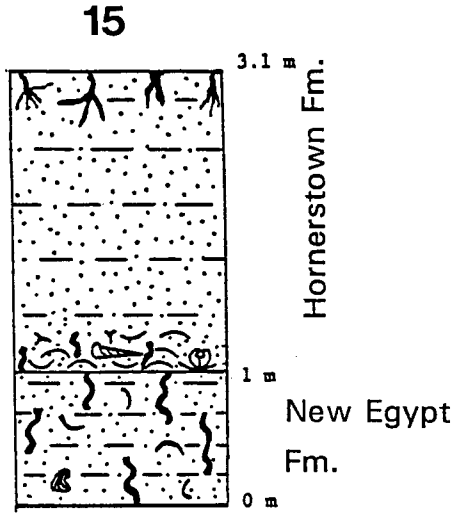

10
6 m
5 m
4 m
3 m
2 m
1 m
0 m
Red Bank Fm.
Navesink Fm.

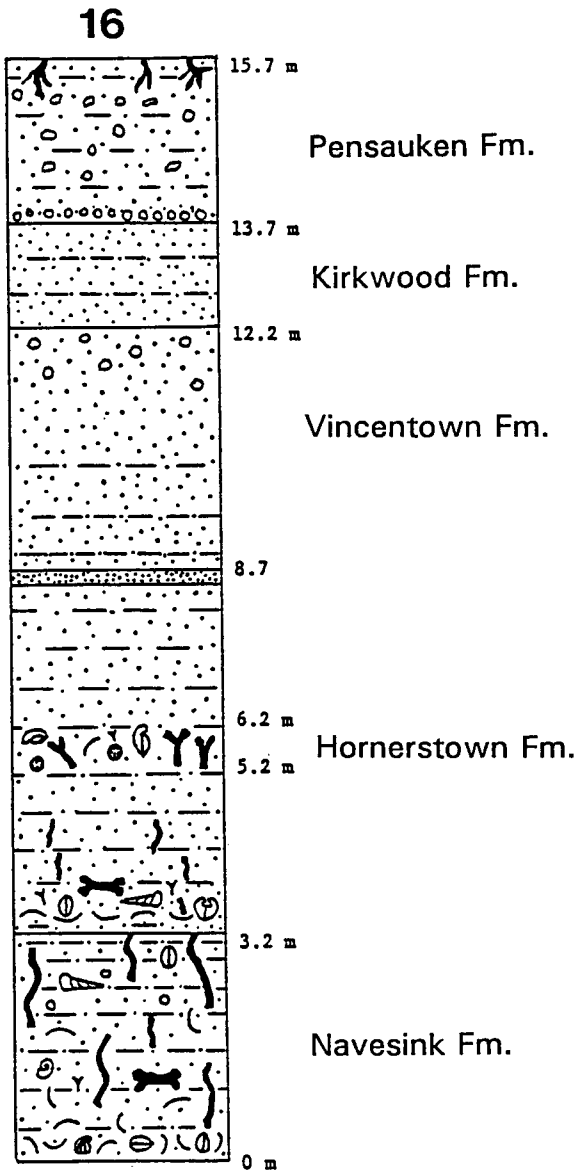

11
15.5 m
12 m
8 m
1 m
0 m
Red Bank Fm.
Navesink Fm.


12
11 m
10 m
8.5 m
6.5 m
1.5 m
0 m
Hornerstown Fm.
Tinton Fm.
Red Bank Fm.
obscured

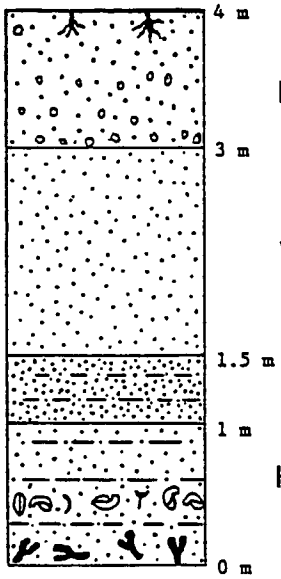

13
2.5 m
2 m
0 m
Tinton Fm.


14
13 m
9.1 m
5.8 m
.3 m
0 m
Pensauken Fm.
Hornerstown Fm.
Navesink Fm.


15
3.1 m
1 m
0 m
Hornerstown Fm.
New Egypt Fm.


16
15.7 m
13.7 m
12.2 m
8.7
6.2 m
5.2 m
3.2 m
0 m
Pensauken Fm.
Kirkwood Fm.
Vincentown Fm.
Hornerstown Fm.
Navesink Fm.

17

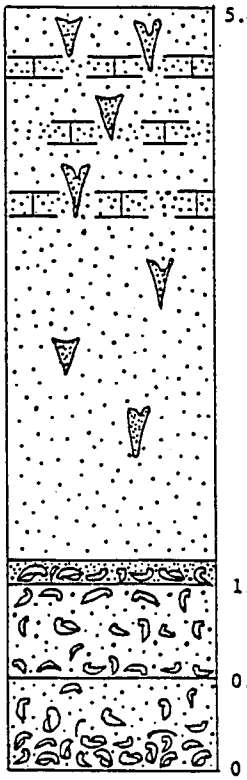


Pensauken Fm.

Vincentown Fm.

Hornerstown Fm.

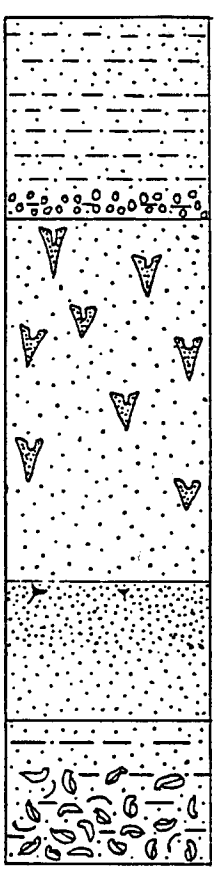
18



Vincentown Fm.

Hornerstown Fm.

19

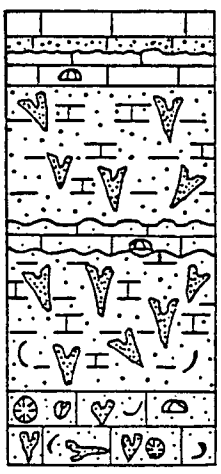


Manasquan Fm.

Vincentown Fm.

Hornerstown Fm.

20



Vincentown Fm.